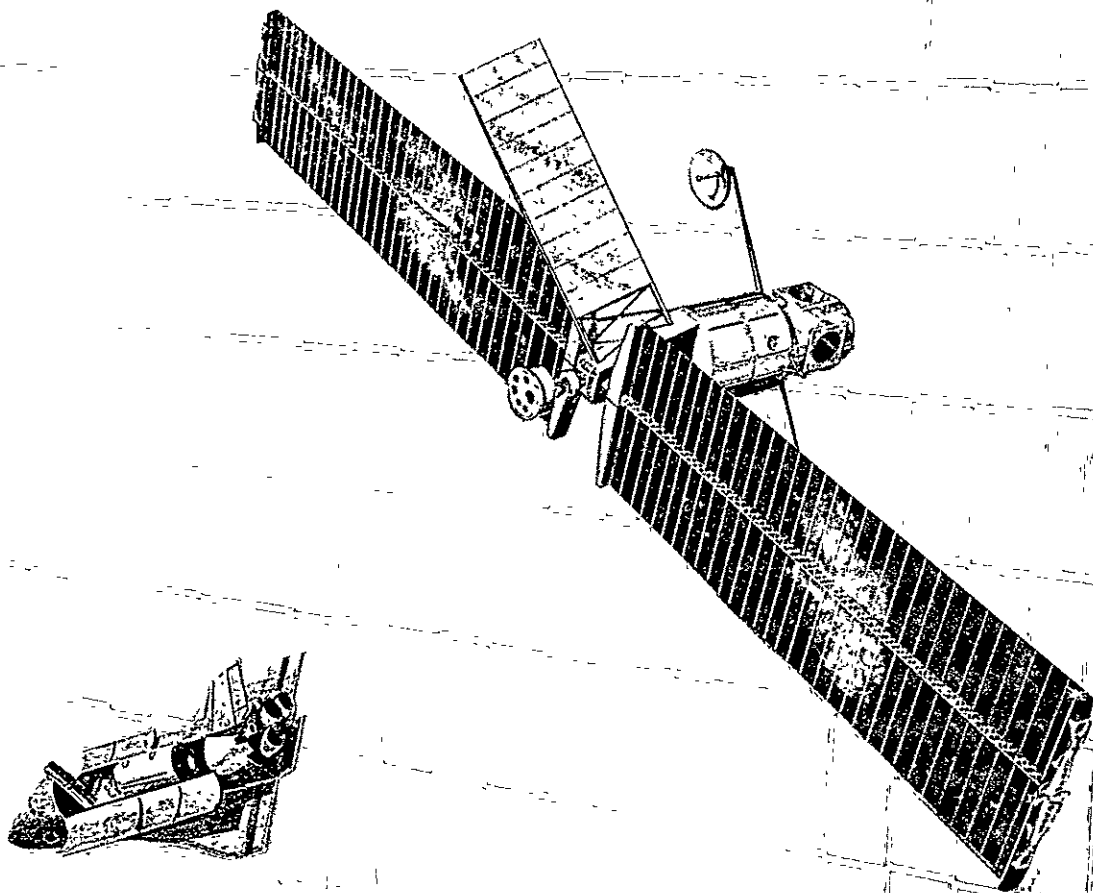


27 JANUARY 1979



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EVOLUTION STUDY, PART 3: CONCEPTUAL
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Space Flight Center

25 kW POWER MODULE EVOLUTION STUDY

VOLUME 2 PROGRAM PLANS

PART III : CONCEPTUAL DESIGNS FOR POWER MODULE EVOLUTION FINAL REPORT

LOCKHEED MISSILES & SPACE COMPANY, INC.

FINAL REPORT

25 kW POWER MODULE EVOLUTION STUDY

PART III: CONCEPTUAL DESIGNS FOR POWER MODULE EVOLUTION

VOLUME 2: PROGRAM PLANS

27 January, 1979

SUBMITTED TO THE
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Marshall Space Flight Center
Huntsville, Alabama 35812

Contract NAS8-32928

DPD 555
DR No. MA-04

LOCKHEED MISSILES & SPACE COMPANY
Sunnyvale, California

FOREWORD

This volume of the Part III Final Report for the 25 kW Power Module Evolution Study was prepared by Lockheed Missiles and Space Company, Inc. for the George C. Marshall Space Flight Center (MSFC). National Aeronautics and Space Administration (NASA), under Contract No. NAS8-32928.

The Objective of the study was to define how the 25 kW Power Module can be evolved by the addition of system elements in evolutionary steps to meet the future mission requirements. For each step, conceptual designs were prepared. The level of capability at each step was commensurate with the mission and payload requirements. Emphasis was placed on the near-term steps beyond the 25 kW Power Module.

The study activity comprised the following parts/tasks:

- o Part I - Payload Requirements and Growth Scenarios (LMSC, TWR, and Bendix)

The analytical effort was conducted to develop payload application summaries and time-phased requirements that will drive the concepts for the 25 kW Power Module and the supporting systems definitions (for the period 1983-1990). The Part I effort was documented in Final Report LMSC-D614921A, dated 1 August 1978.

- o Part II - Payload Support System Evolution (LMSC, IBM, Bendix)

This effort was devoted to establishing baseline program support elements and candidate evolutionary growth capabilities for final candidate definition (element, data, cost, mods, development sequence, and precursor missions).

The Part II effort was documented in Final Report LMSC-D614928A, dated 30 September 1978.

- o Part III - Conceptual Designs for Power (LMSC, Bendix)
Module Evolution

This effort was conducted to establish design approaches for the evolutionary systems, to develop associated programmatic data, and to assess the evolution scenario and capabilities of the 25 kW Power module for representative missions.

This report constitutes Volume 2, Program Plans of the Part III Final Report. It meets the requirements of Contract No. NAS8-32928 Data Procurement Document, Data Requirement MA-04, Final Study Report.

The volumes comprising the Part III Final Report are:

- o Volume 1 Power Module Evolution
- o Volume 2 Program Plans
- o Volume 3 Cost Estimates
- o Volume 4 Design Analyses
- o Volume 5 Mission Accommodations
- o Volume 6 WBS and Dictionary

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Section 1

INTRODUCTION

1.1 PURPOSE

This document is a plan for evolutionary development of a Power Module System for major space missions in the 1983-1990 time span. The plan anticipates the scope of future resource requirements, and presents an orderly and timely program to establish and operate growth-oriented Space Power Module capabilities.

1.2 PROGRAM OBJECTIVE

The Power Module System program objective is to provide on-orbit support capabilities for earth orbit space missions in accordance with anticipated user requirements and practical funding projections. These on-orbit support capabilities must provide electrical power, attitude control, thermal control and heat rejection, rendezvous, berthing and docking, communications, command and data handling for operations compatible with the Orbiter, Spacelab and payload systems. The system developed initially will meet lower user requirements and has growth potential to evolve throughout the decade in steps to provide higher capacity systems in a practical and cost effective manner.

1.3 SCOPE

The scope of this plan is confined to development and deployment of the Power Module System with performance capabilities required to support the 1983 to 1990 user requirements as defined in the Part I Final Report (Reference 1).

This plan presents a summary of the program functional, operational, and hardware elements; program work breakdown and specification items; development plans and schedules for developmental and technology milestones; test concepts and timelines; and ground and orbit operations concepts.

Section 2

PROGRAM SUMMARY DESCRIPTION

2.1 PROGRAM CONCEPTS

The Power Module System utilizes a spaceborne platform which contains solar cells to convert sun radiated energy directly into electrical power. Electrical energy is either directly regulated, distributed and used, or stored in power module batteries to support on-board housekeeping requirements and user power requirements. The Power Module System also includes provisions for heat rejection, thermal balance maintenance, nominal pointing and attitude control, command and data handling, and berthing and docking operations.

The Power Module employs the low earth orbit placement and supporting services capabilities of the Space Transportation System (STS). After delivery into orbit, the Power Module functions in either a sortie mode when connected with the Orbiter or other spacecraft; or, alternatively, as a free-flyer providing extended unmanned and manned support in combination with various user(s) needs.

The Power Module System employs three basic, evolutionary system growth modules: (1) a 25 kW Power Module, (2) a 50 kW Power Module, and (3) a 100 kW Power Module. The fully developed system readily provides required on-orbit capability appropriately sized for specific mission applications or sets of mission applications, Figure 2-1. Growth is achieved in a manner that augments previously developed capabilities for cost effective application to future user needs. Figure 2-2 illustrates the basic concept of modular growth from common elements. Increased requirements for solar array area, batteries and heat rejection are accommodated through various combinations of direct addition, substitution and technology advances.

Figure 2-3 presents configuration details of the 25 kW Power Module, the basic building block for the evolutionary Power Module System. Using this module, the derived system configurations depicted in Figure 2-4 are developed responsive to the various mission requirements designated for Scenario I

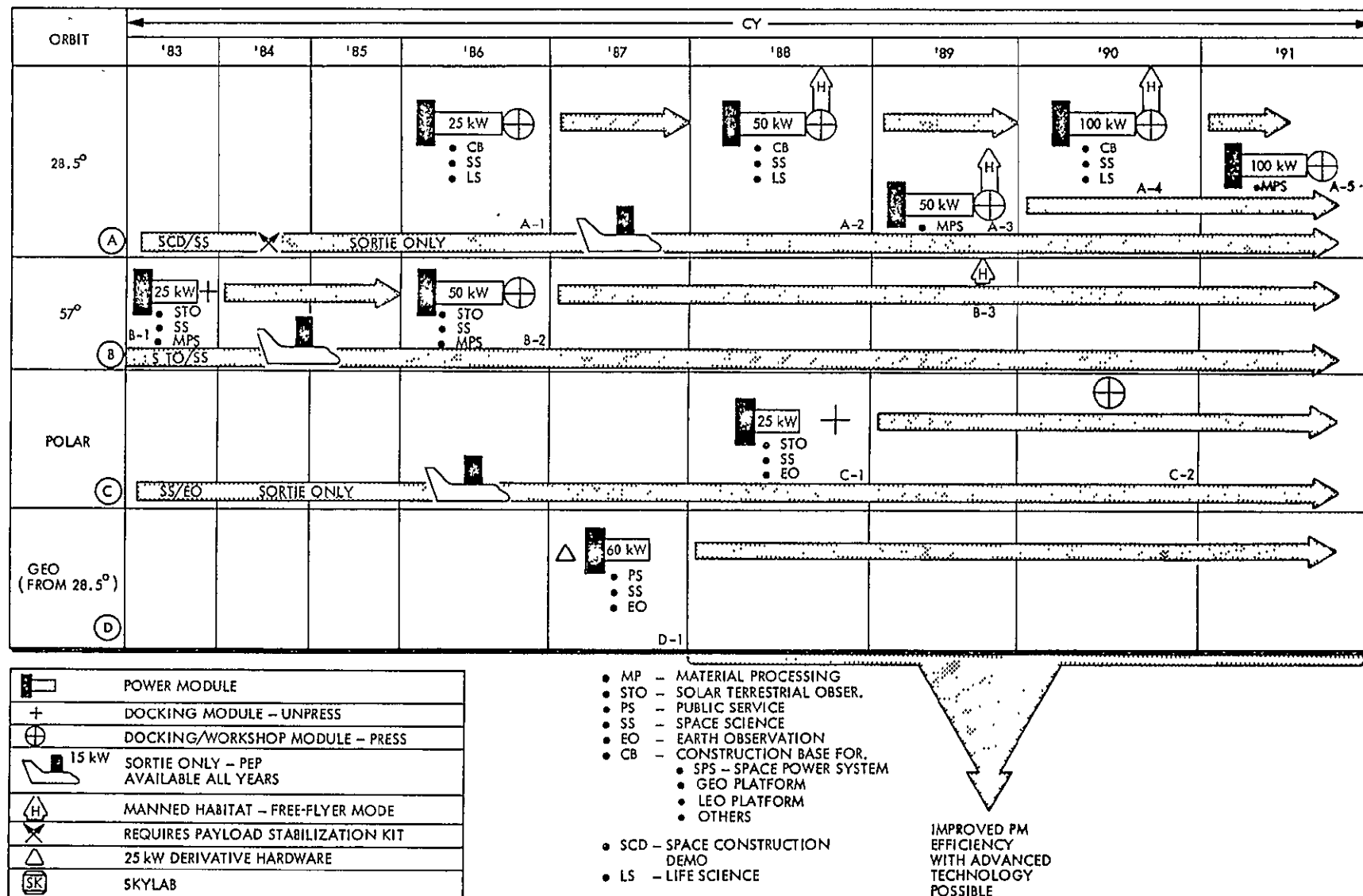


Figure 2-1. Scenario I Power Module System Evolution

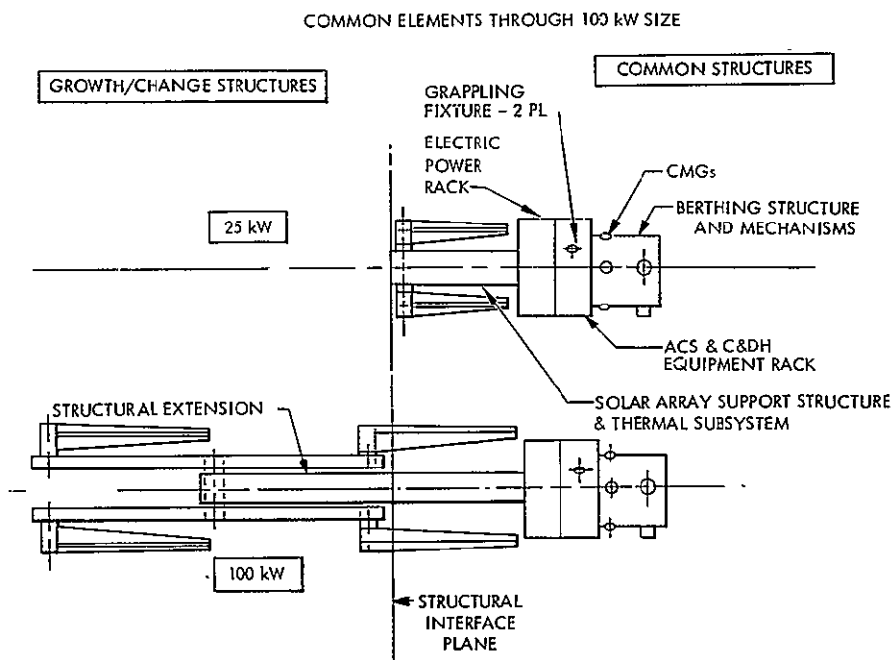


Figure 2-2. Modular Growth

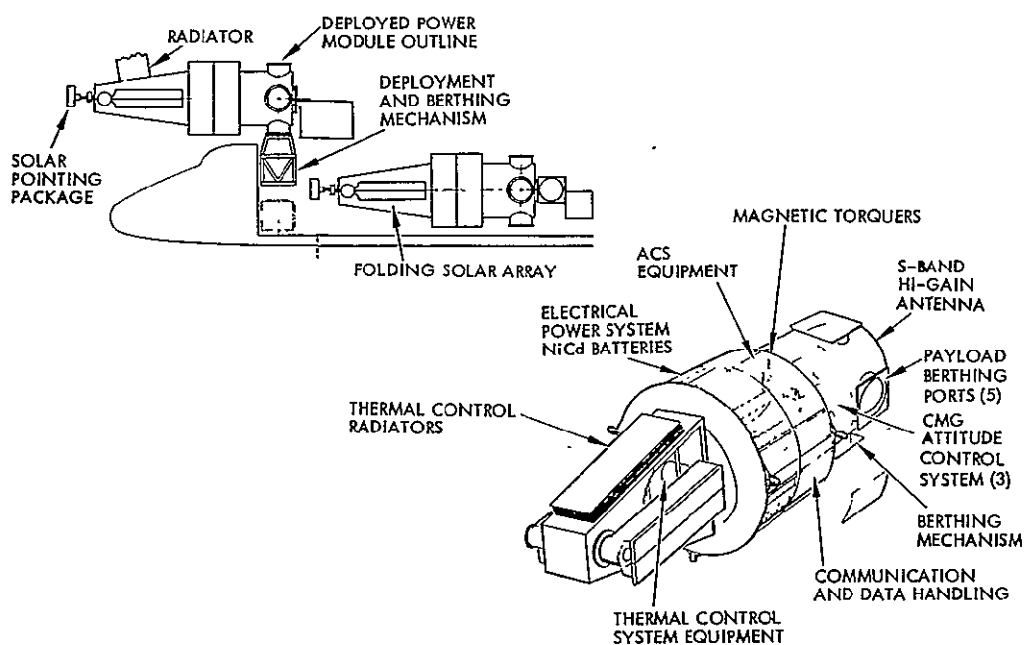


Figure 2-3. 25 kW Power Module Configuration Details

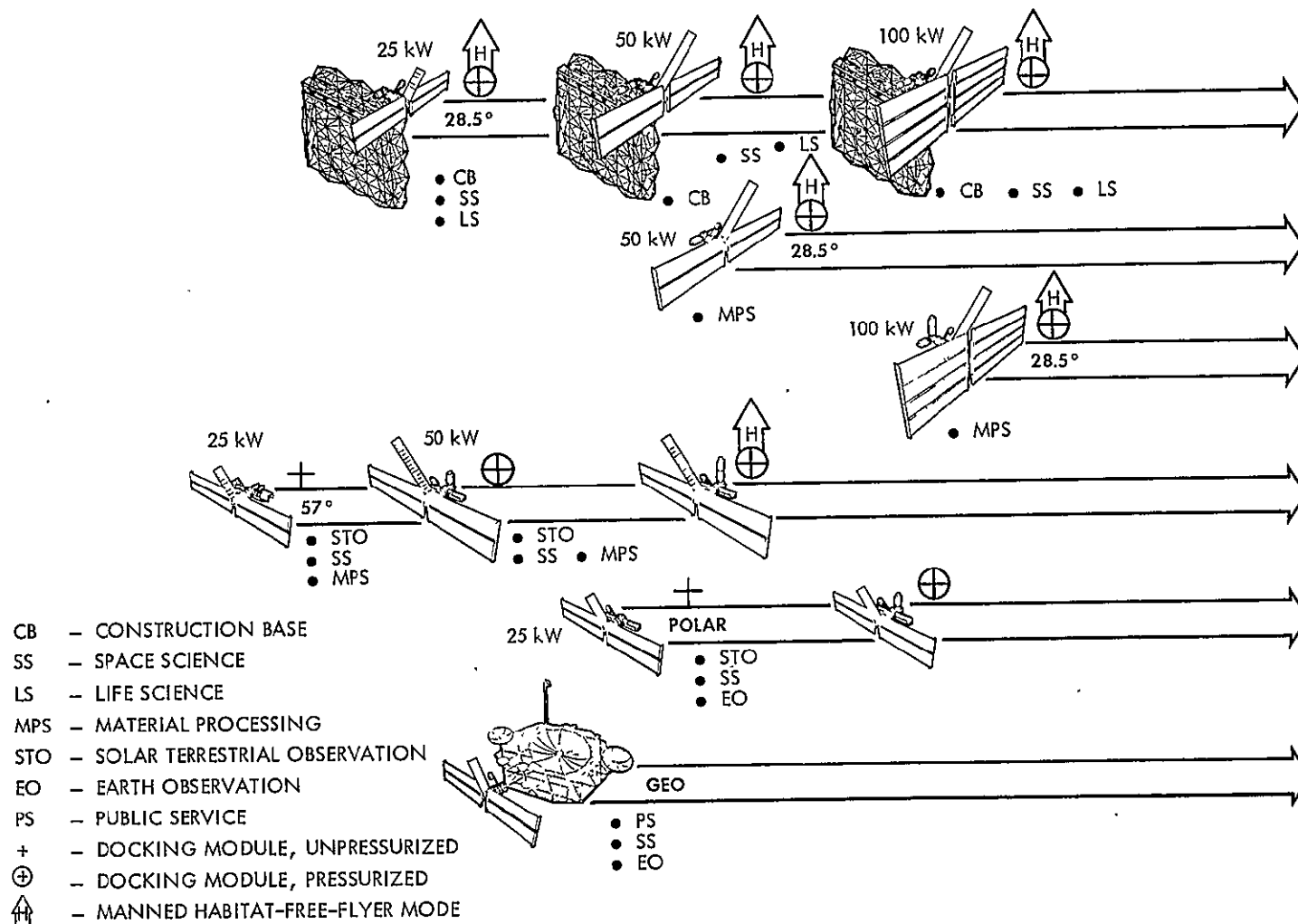


Figure 2-4. Derived Payload Support System Configuration

(Figure 2-1). For these applications, a number of support items have been identified and are presented in Figure 2-5. It should be recognized that these support elements are presumed to be available to support the various payloads assigned to the Power Module System and that their development, production, testing and operation is not within the scope of the planned Power Module System.

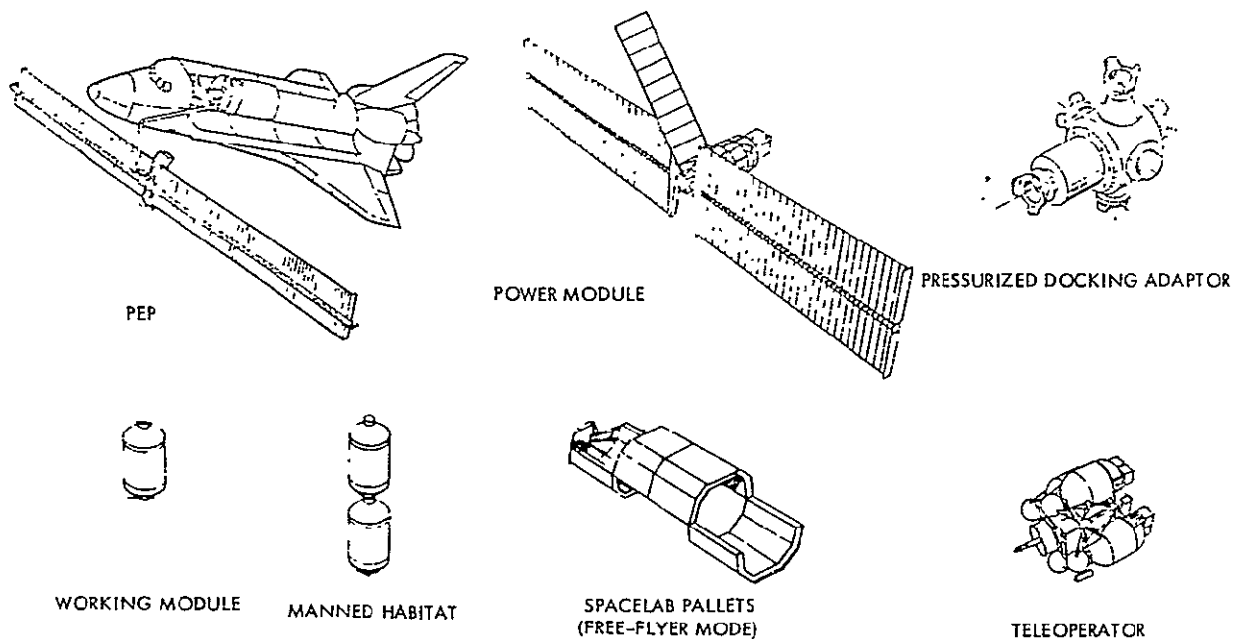


Figure 2-5 STS Enhancement System Support Elements

2.2 POWER MODULE PERFORMANCE REQUIREMENTS

The initial (25 kW) Power Module is more fully defined in Volume 1 of the Part III Final Report, (Reference 2). The performance requirements for the 25kW Power Module are summarized below:

Operations:	IOC-October 1983
	Life - 5 years on orbit
	Maintenance - on orbit via EVA

Refurbishment - Return to earth

Duty Cycle - 50%

Operational Modes: Sortie - Orbiter/Payload attached to Power Module
 Free-Flying - Payload attached to Power Module
 Orbital Storage - Standby Power Module

Performance General: o Provide EVA access
 o Provide 25 kW output (to Berth Interface)
 o Provide one degree of freedom in solar array -
 full and partial retraction
 o Provide stabilization and control
 - PM and Orbiter in berthed/docked sortie mode
 - PM and attached Payloads in Free-Flyer mode
 o Provide limited heat rejection for Orbiter/
 Payloads
 o Provide Communication compatible with TDRSS
 and Orbiter and PM System status data
 o Provide berthing/docking capability with
 Orbiter/Payloads
 o Provide capability for Orbiter bay deployment
 and retrieval

2.3 PROGRAM ELEMENTS

The program elements are identified at the summary (down to Power Module Subsystem) level in Figure 2-6. The three basic elements of the complete Power Module System are the 25 kW Power Module, the 50 kW Power Module and the 100 kW Power Module. These power modules are depicted in Figures 2-7, 2-8, and 2-9. The common elements among the several modules are evident. It is essential, however, that the identification of each Power Module be complete for that specific program's elements. Volume 6 of this Part III Final Report (Reference 3) provides a more complete Work Breakdown Structure (WBS) and Dictionary of System Elements.

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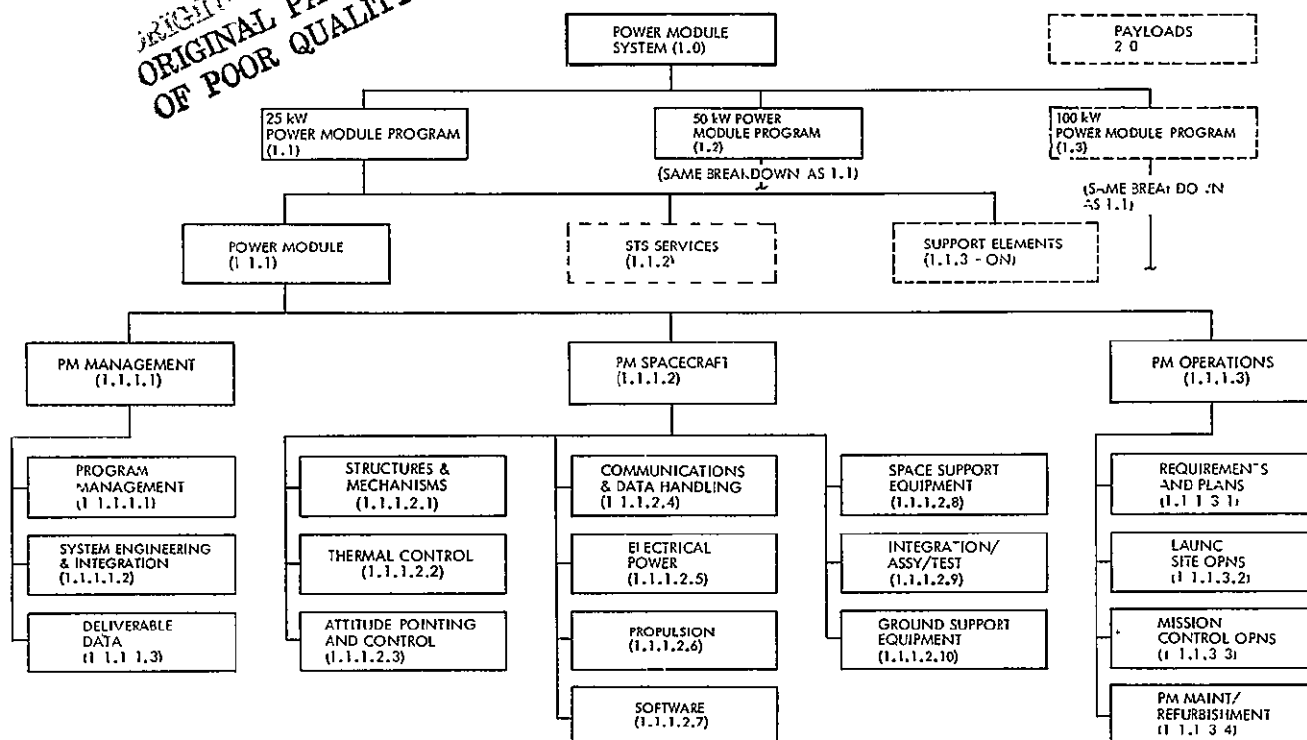


Figure 2-6. Program Elements

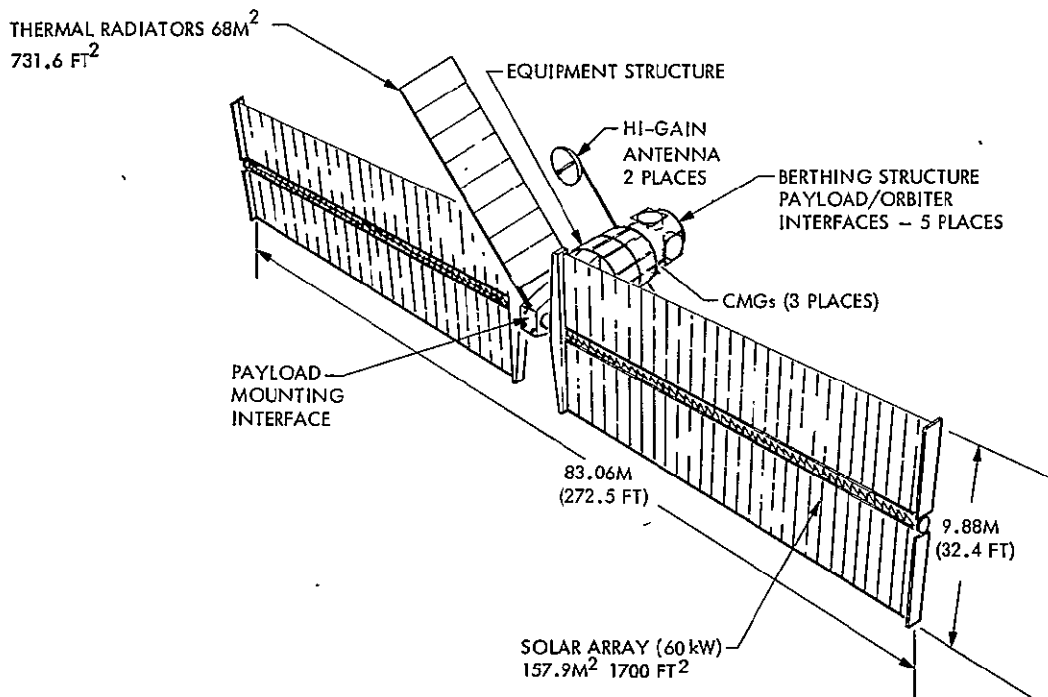


Figure 2-7 25 kW Power Module Configuration - Deployed

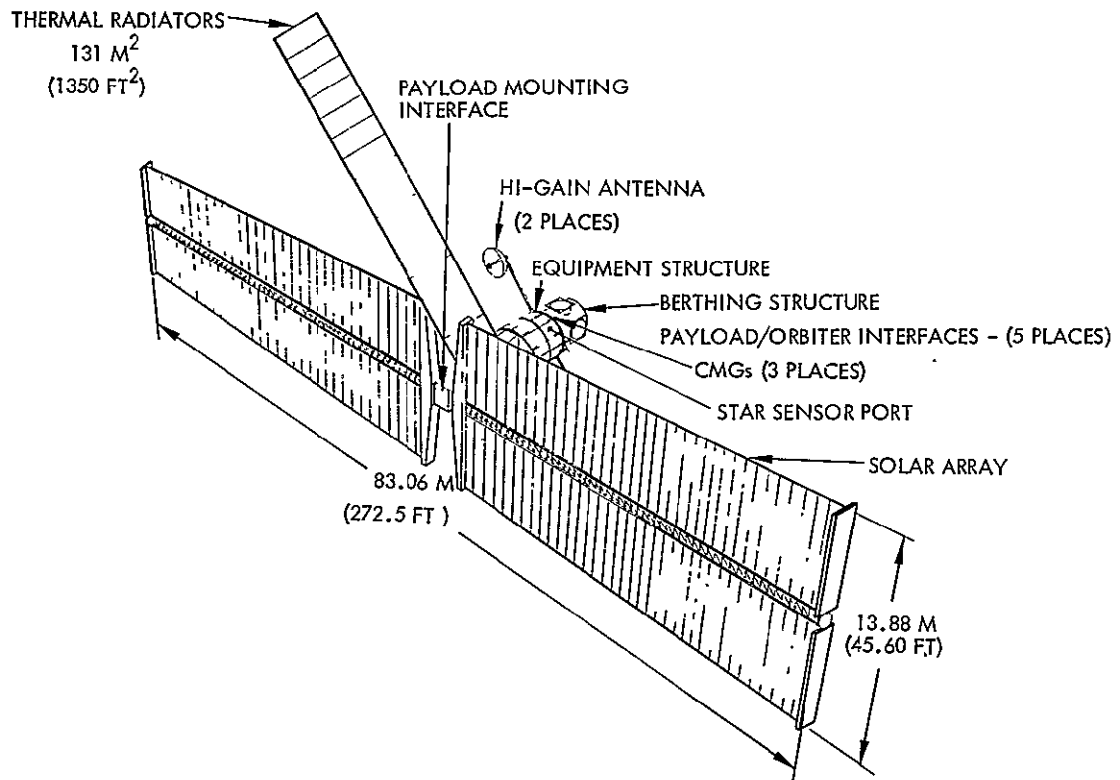


Figure 2-8 50 kW Power Module

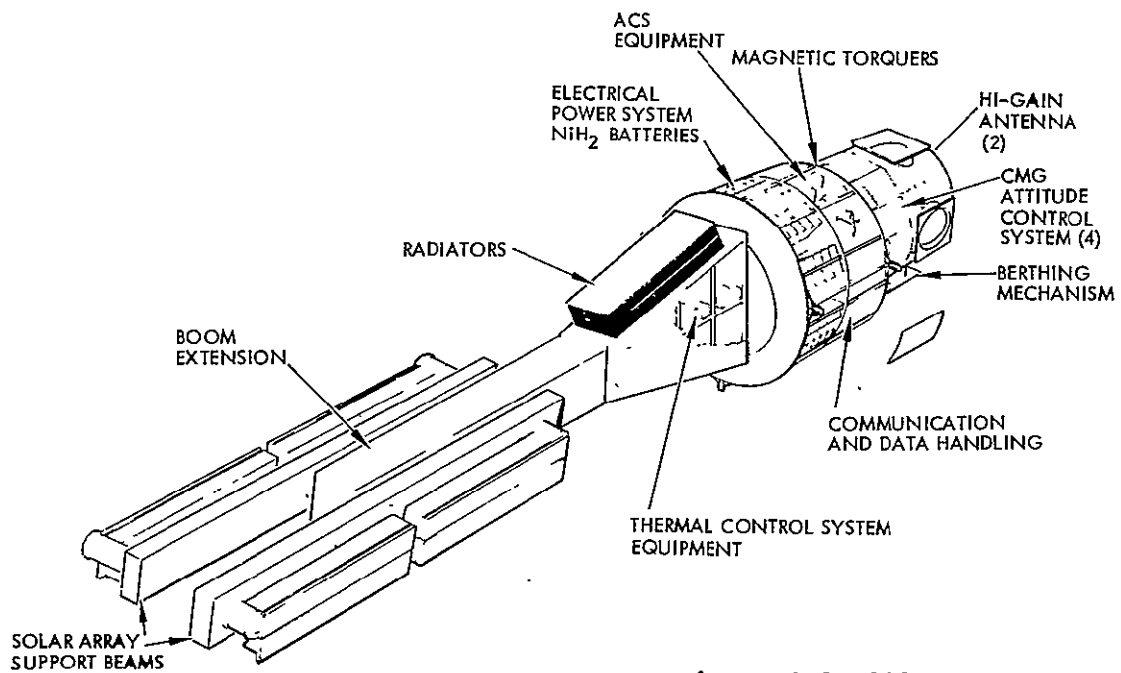


Figure 2-9 100 kW Power Module
Inboard Profile

Each configuration uses two cylindrical rack structures, solar array wings mounted on support structures, and a berthing structure module. The arrays have single degree-of-freedom about the long axis for solar pointing. Control moment gyros (CMGs) are used for orbit stabilization and control. Flat panel-type radiators mounted on the array support structure are used for heat rejection from the power module and from the Orbiter/Payload. Principal hardware system elements are described by the following paragraphs.

2.3.1 Structure and Mechanisms Subsystem (SMS)

The Structure Subsystem comprises two equipment racks mounted in tandem arrangement. The solar array support structure is mounted to the forward rack and supports the array assembly. The berthing module structure is attached to the aft rack. The SMS also includes a number of small mechanisms associated with latching, locking, berthing, bracketry, and fittings.

2.3.2 Thermal Control Subsystem (TCS)

The Thermal Control Subsystem consists of 10 double surface radiators that are hinged and stowed for launch, then unfolded and extended into position for orbit operations. A freon fluid loop is provided for cooling.

2.3.3 Attitude Pointing & Control Subsystem (APCS)

The Attitude Pointing & Control Subsystem uses sun sensors, rate gyros, and Control Moment Gyros (CMGs) in conjunction with the Communication and Data Handling Subsystem digital computer to sense, evaluate and control power module stability and flight orientation. A magnetic torquing system is installed to provide redundant stabilization for vehicle retrieval requirements and to provide for CMG desaturation. The attitude determination system consists of three NASA Standard Fixed-Head Star Trackers and provides the reference for experiment pointing and computing antenna pointing angles.

2.3.4 Communication & Data Handling (C & DH) Subsystem

The Communication & Data Handling Subsystem encompasses the on-board equipment and functions associated with command, control, communications, switching, cabling and data handling. The NSSC-II Computer will be utilized. A steerable S band antenna and related steering control, drive assembly, deployment and retraction assembly are specifically included. All interconnect cabling, wiring and switching components are also included.

2.3.5 Electrical Power Subsystem (EPS)

The Power Module EPS is comprised of a Power Source, Energy Storage, and Power Distribution hardware. Solar arrays provide the power source. Power is distributed through appropriate distribution control units to other PM systems and provides power to the Orbiter interface.

2.3.6 Propulsion Subsystem (PS)

The Power Module Propulsion Subsystem is to be defined (TBD).

2.3.7 Software

Two categories of software function in direct support of the Power Module: Flight Operations Software and Ground Test Software. Flight software computer programs are designed, developed, verified, and used directly in the NSSC-II digital computer to perform all onboard PM flight functions. Ground test software computer programs are designed, developed, verified and used in the NSSC-II digital computer to perform ground tests of the Power Module System. Certain ground test computer programs will be used directly in Ground Support Equipment to program test sequences, and evaluate performance data.

2.3.8 Space Support Equipment (SSE)

Space Support Equipment is flight hardware to be installed in the Orbiter as required to support operational deployment, operation, maintenance, retrieval,

and transport (launch and return) of the Power Module. SSE includes hardware used to secure, monitor, command, control, berth, and otherwise support Power Module operations.

2.3.9 Ground Support Equipment

Ground support equipment is ground hardware (electrical and mechanical) used to handle, transport, service, verify, and checkout the Power Module during fabrication, assembly, factory test, and launch site testing.

2.3.10 Applicable Documentation and Specifications

A table of applicable program documents required for implementation of the Power Module Program development and production phase is presented in Fig. 2-10. Most of these documents will be produced during the Program Definition (Phase B) effort.

2.4 PROGRAM MASTER SCHEDULE

The master schedule for development, deployment and operation of the Power Module System in support of Scenario I is presented in Figure 2-11. Start date for the development program is October, 1980, co-incident with the beginning of Fiscal Year 1981. The first 25 kW Power Module is developed, produced, launched into a 57° orbit, checked out and readied for operational use 36 months later, in October 1983. The Initial Operational Capability (IOC) for the 25 kW Power Module Program is that point in time when it is first ready to serve the operational requirements of the user payloads.

The first Power Module is identified as FV-1. The configuration provides Orbiter cargo bay space and weight accommodation for initial mission operational payloads deployment on the Power Module initial deployment flight. Reduced STS user costs and reduced risk for total mission success is obtained by combining FV-1 and its initially assigned payload in the same prelaunch and launch operations.

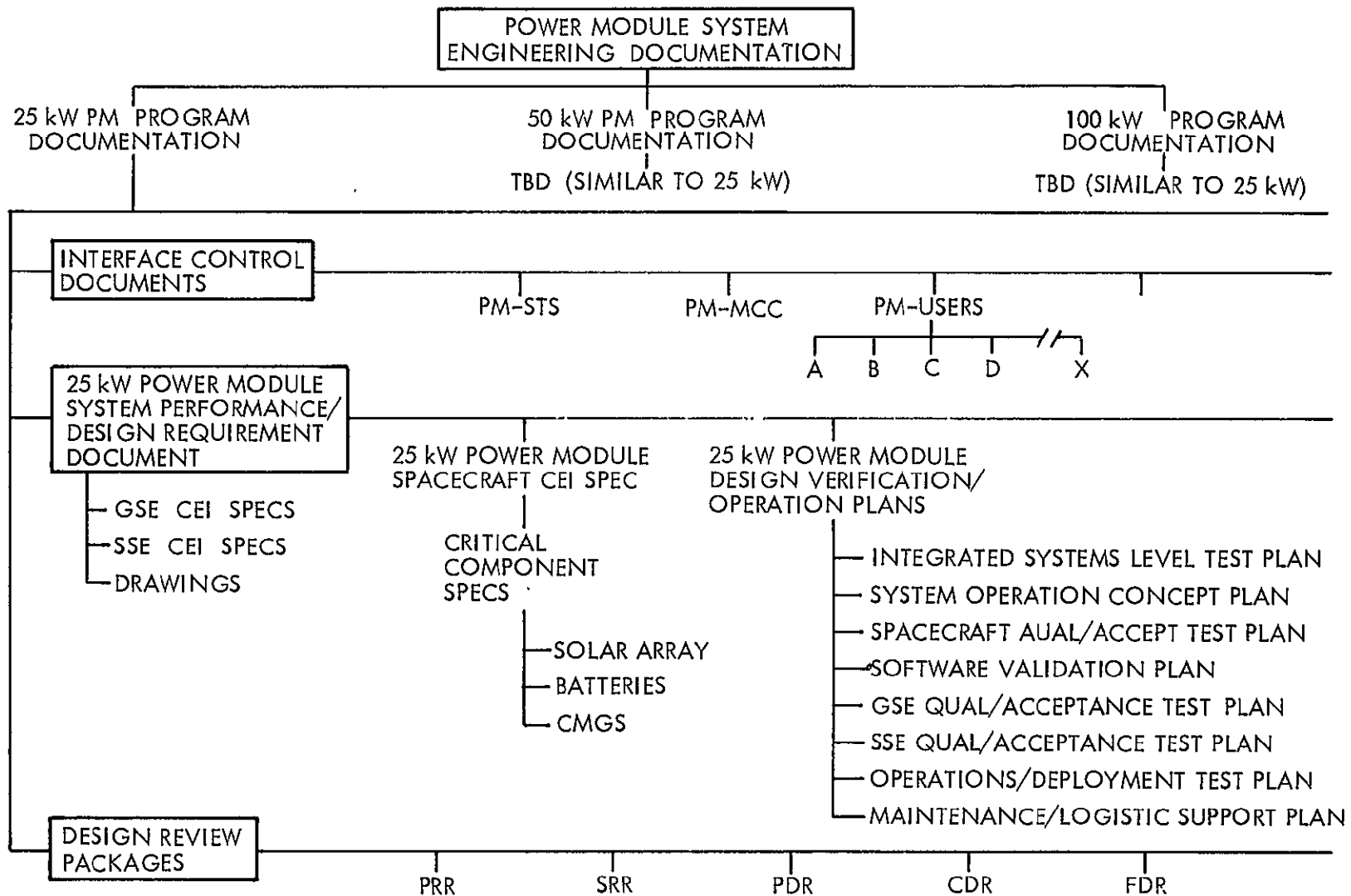


Figure 2-10 Summary of Engineering Documentation

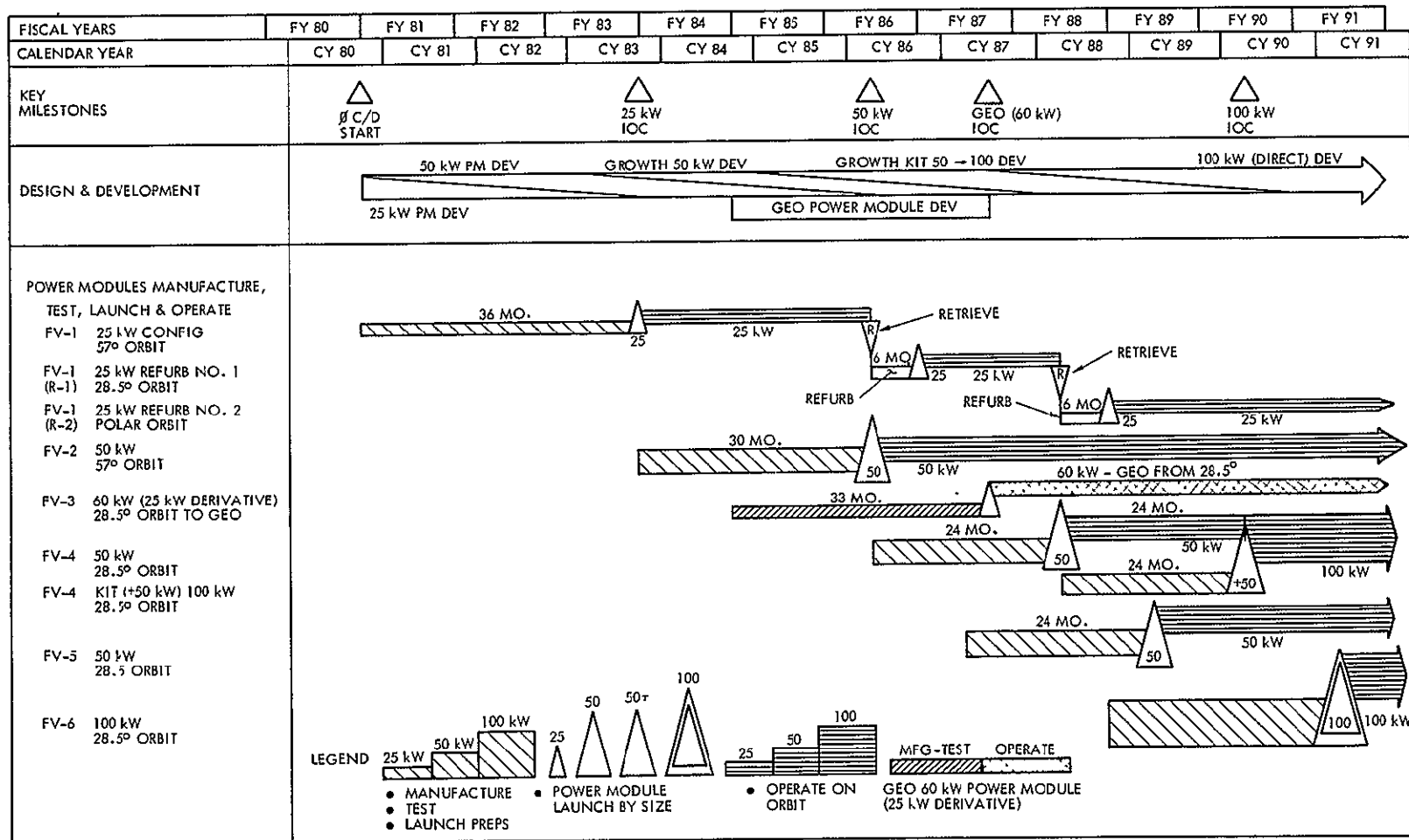


Figure 2-11 Scenario I Master Schedule

FV-1 is planned for 30 months of orbital operation and then is retrieved for later deployment in a 28.5° orbit. At this point in the Scenario, mission requirements call for a 50 kW Power Module in the 57° orbit. FV-2 is therefore provided as a 50 kW Power Module. FV-2 will then be operated with various payloads for the remaining period of the Scenario (through 1991). Essential on-orbit maintenance and servicing is provided in the course of payload revisit operations.

FV-3 is a special derivative power module from the 25 kW Power Module which is deployed in geosynchronous orbit. Although its power level requirements are approximately 60 kW, this level is achieved without increase in the 25 kW Power Module solar array because of the near constant exposure to the sun. Definition of this power module is quite limited at this time. Therefore, as a simplification, this GEO power module is assumed to require the same approximate manufacturing, test and launch activity spans as the low earth orbit power modules.

The second 50 kW Power Module is manufactured with provisions for future growth, on orbit, to a 100 kW capability. This unit, FV-4, replaces the refurbished FV-1. The growth kit for FV-4 is identified as FV-4K. The principal element of the growth kit is a second solar array complement, similar to the initial 50 kW array, plus added solar array support structure. The added structure is also designed to accommodate additional batteries as needed.

FV-1, following its second retrieval (CY 1988) is refurbished and then placed in a polar orbit for the remainder of the Scenario and beyond. In each recycle of the FV-1, a 6-month refurbishment span is provided. These activities and associated timelines are presented in detail later in this volume (Section 5.1.3).

FV-5, the third 50kW produced and launched, is deployed in 1989. It becomes the second 50kW unit in operation in a 28.5° orbit at that time. The first unit, FV-4, is expanded to a 100kW Power Module early the following year by growth on orbit with the FV-4K augmentation kit.

The final unit, FV-6, is a 100kW Power Module which is also deployed into a 28.5° orbit. This is accomplished by using two Orbiter flights. One flight requires a full Orbiter payload; the second uses only about one-third of an Orbiter mission payload capability. It is therefore assumed and planned that the remaining two-thirds of the Orbiter payload capacity can be effectively combined with the 100 kW Power Module user's STS delivery requirements for mission sharing expediency and cost effectiveness. This 100kW Power Module deployment thereupon results in two 100kW Power Modules operating in the 28.5° orbit concurrent with the remaining 50kW Power Module, FV-5.

Section 3
DEVELOPMENT PLANS AND SCHEDULES

The Master Schedule for Scenario I which was presented in the preceeding section is based in part upon a 36 month 25 kW Power Module development schedule. That development schedule is dependent upon the following programmatic assumptions:

- a. A definition phase precedes start of the development program by a period of 12 months.
- b. Start date for the Development Program is October 1980 (FY81).
- c. A proto-flight concept is employed minimizing development test hardware. Hardware is generally built to fly.
- d. The solar arrays will be furnished by the Power Module Program Contractor. They will initially mate at the launch base; therefore fit and function checks with the Power Module are required using special test hardware and simulation.
- e. The SEPS Technology and Orbital Flight Test Programs are successfully completed on or about the presently scheduled dates.
- f. The Bendix Control Moment Gyros (CMGs) incorporated into the Power Module design are available (in sufficient quantity for the first Power Module) for modification by Bendix upon development program go-ahead.
- g. Planned availability for then-existing designs and hardware is effected as required to support the 25 kW Development Program. Key items included in this assumption are:

Space Telescope SSM Equipment Rack

NSSC-II Computer

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S-Band Steerable Antenna
Solar Cell/Array Technology

- h. Development and Qualification testing will be accomplished at lowest practical component levels of assembly.

Figure 3-1 is a Summary Schedule Network, oriented to the Work Breakdown Structure. The network supports the 25 kW Power Module Development Schedule presented in Figure 3-2. The schedule provides for a Program Requirements Review two months into the Development Program, followed by a 25 kW Power Module Preliminary Design Review (PDR) by the middle of the sixth month. A Program Critical Design Review (CDR) is planned at the end of the thirteenth month.

A Configuration Inspection (CI-1) is initially planned at the completion of final assembly of the first Power Module, followed by a second Configuration Inspection (CI-2) at the end of the Power Module vehicle-level test activity.

Launch site activities are based upon test and operations time-lines which are fully compatible with KSC and STS-Orbiter planning guidelines (Reference 4).

Figures 3-3 through 3-6 are more detailed networks covering the 25 kW PM sub-systems. The schedule is low-risk development, with the pacing item being the solar array wings. Current progress in the state-of-the-art SEP wing gives additional confidence to the schedule proposed for the 25 kW PM.

Figure 3-7 presents the development and production schedule for the solar array assemblies. These assemblies are mated to the Power Module at the launch site. Power Module-Solar Array interface checks will be performed with special tooling during Power Module final assembly and vehicle test.

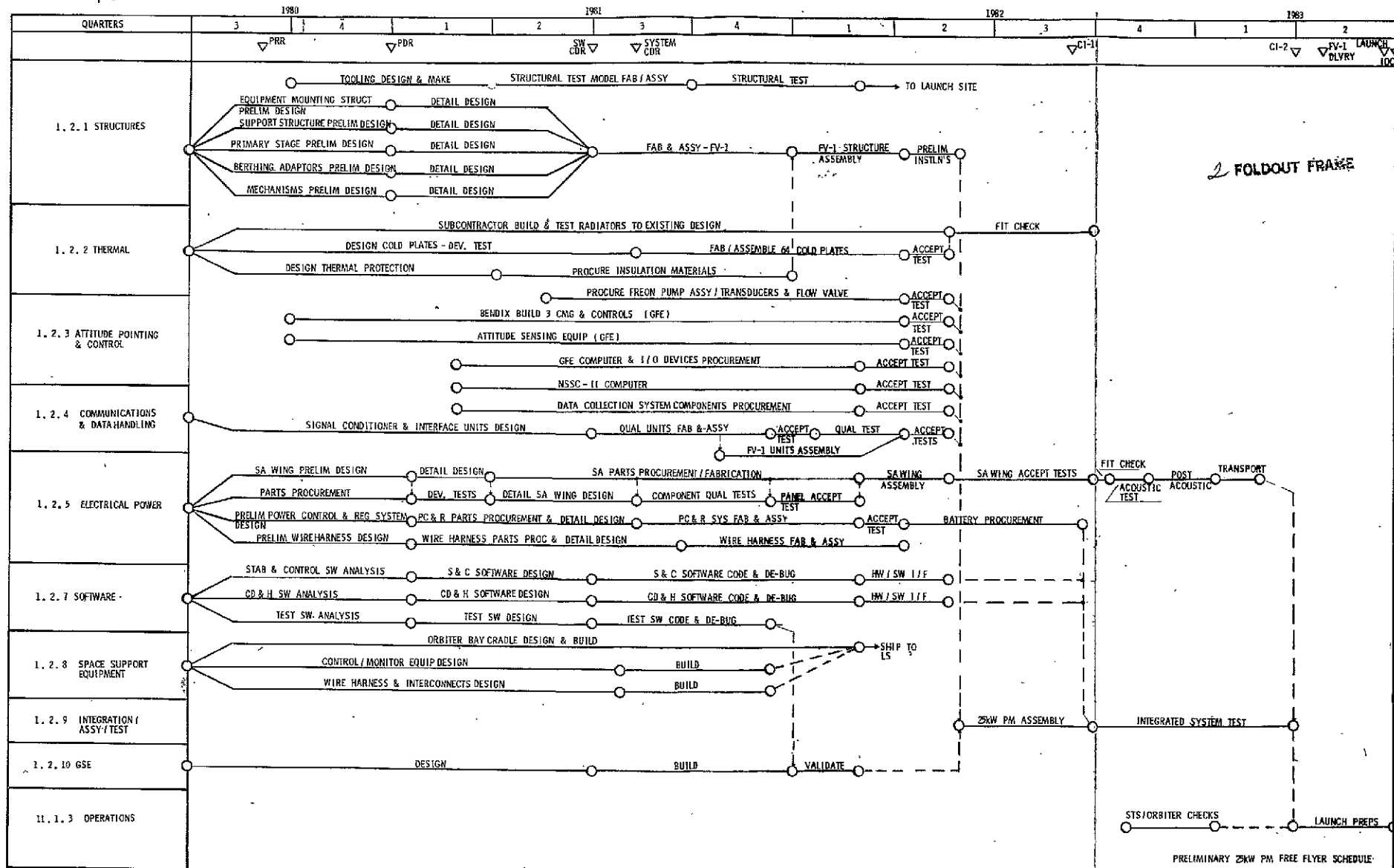


Figure 3-1 Scenario I Summary Logic Network - ZKW Development Program

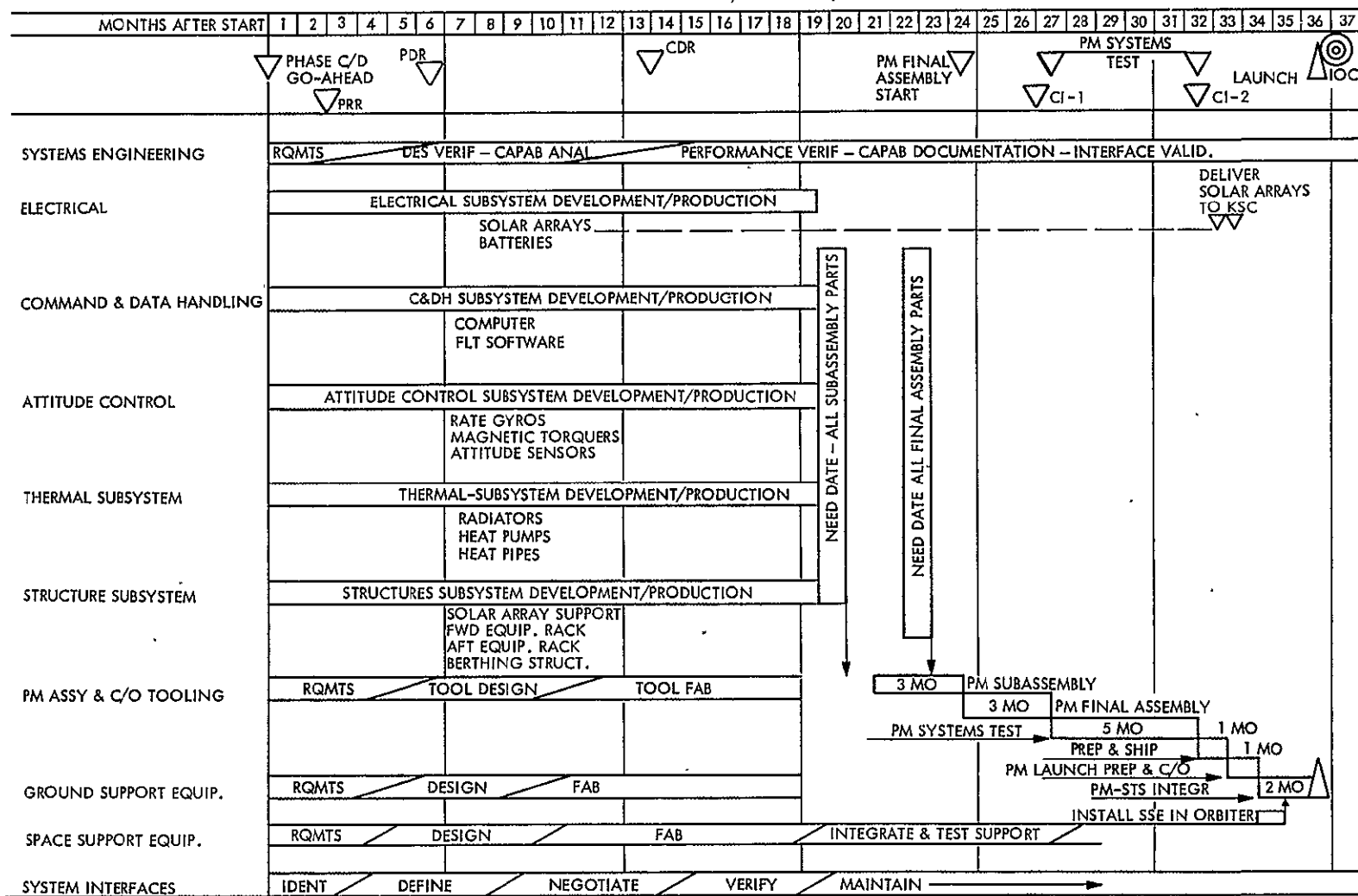
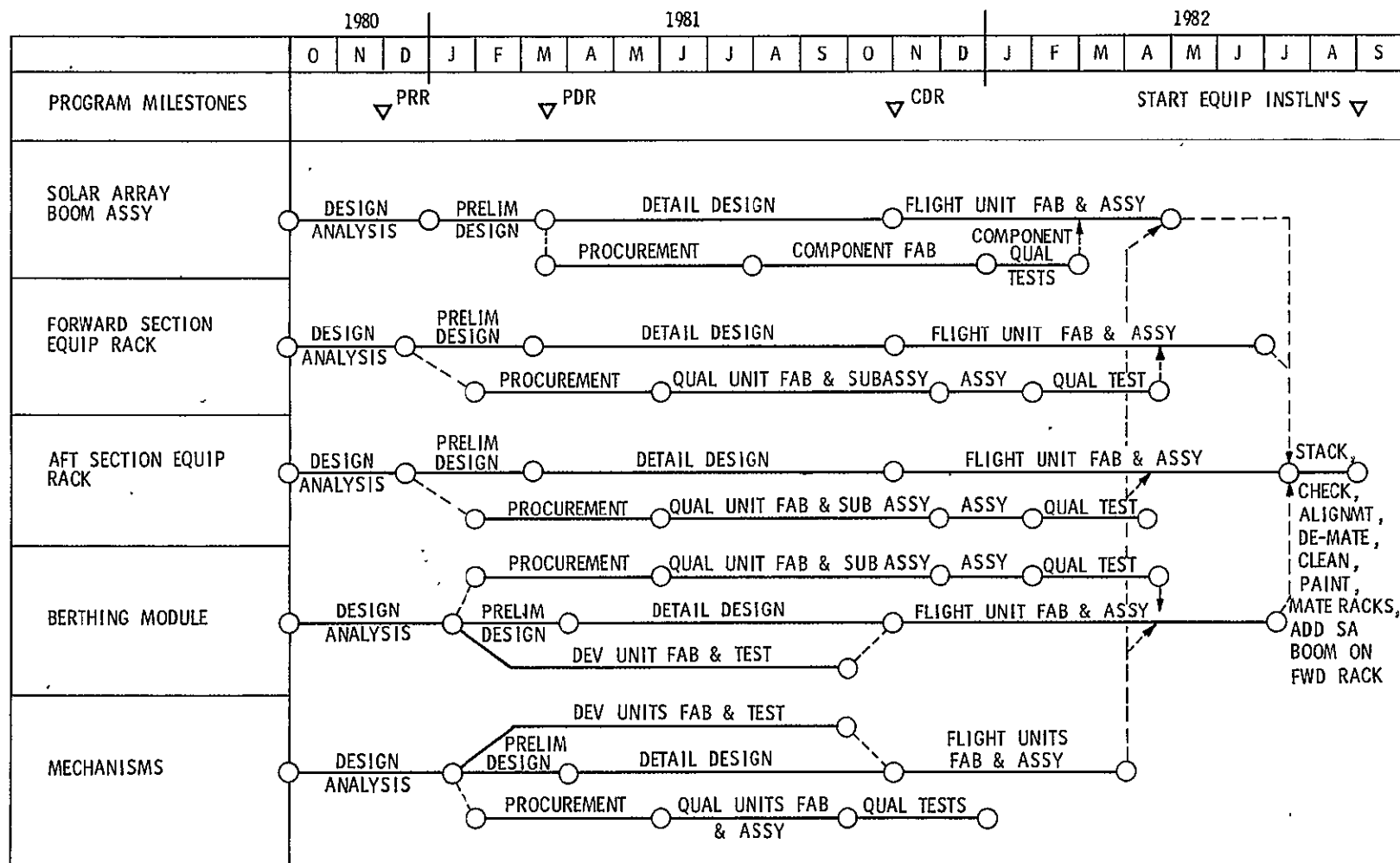


Figure 3-2 25 kW Power Module Development Schedule



25 KW PM STRUCTURE SCHEDULE

Figure 3-3 Structure Subsystem Development Network

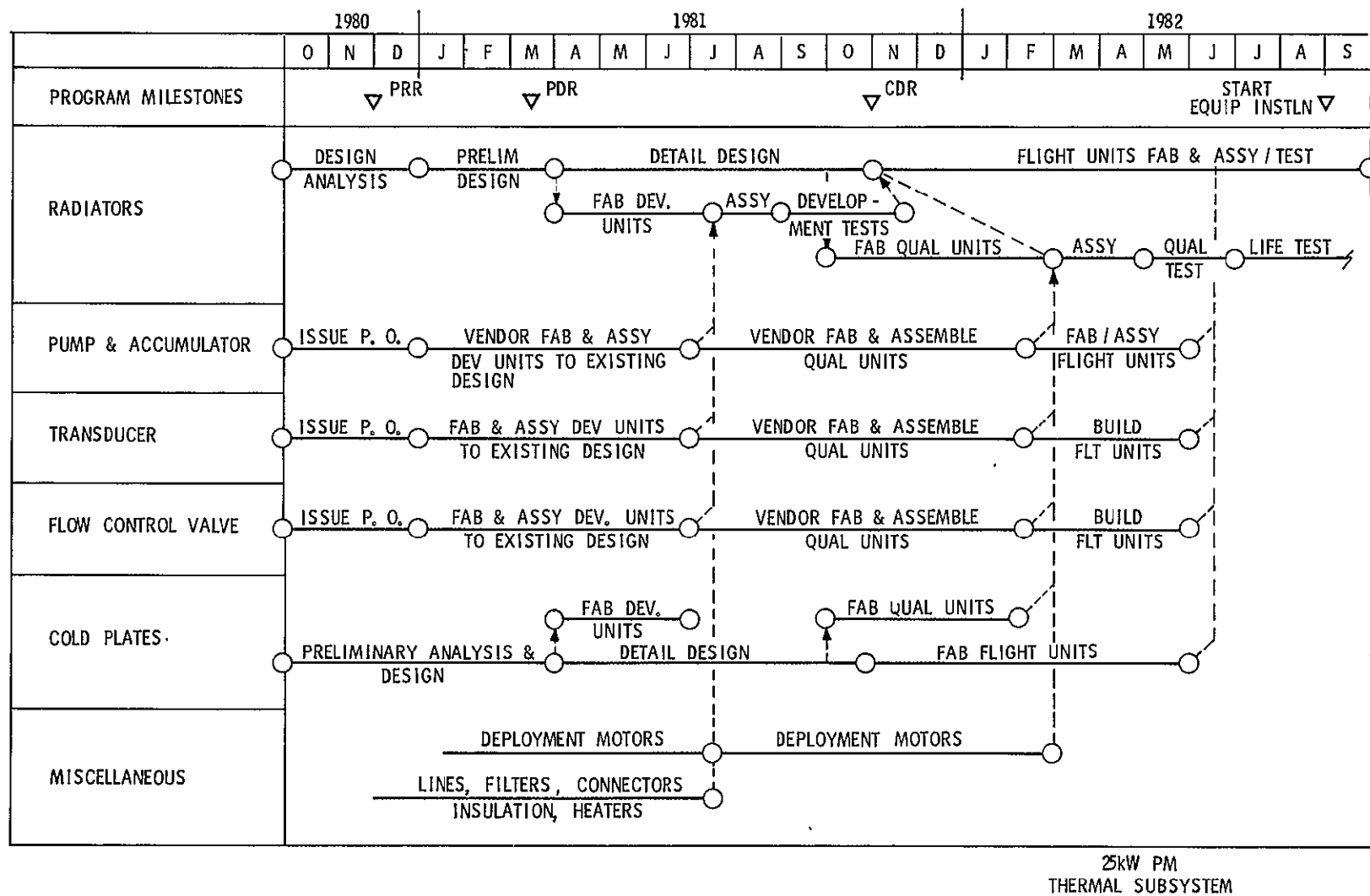


Figure 3-4 Thermal Control Subsystem Development Network

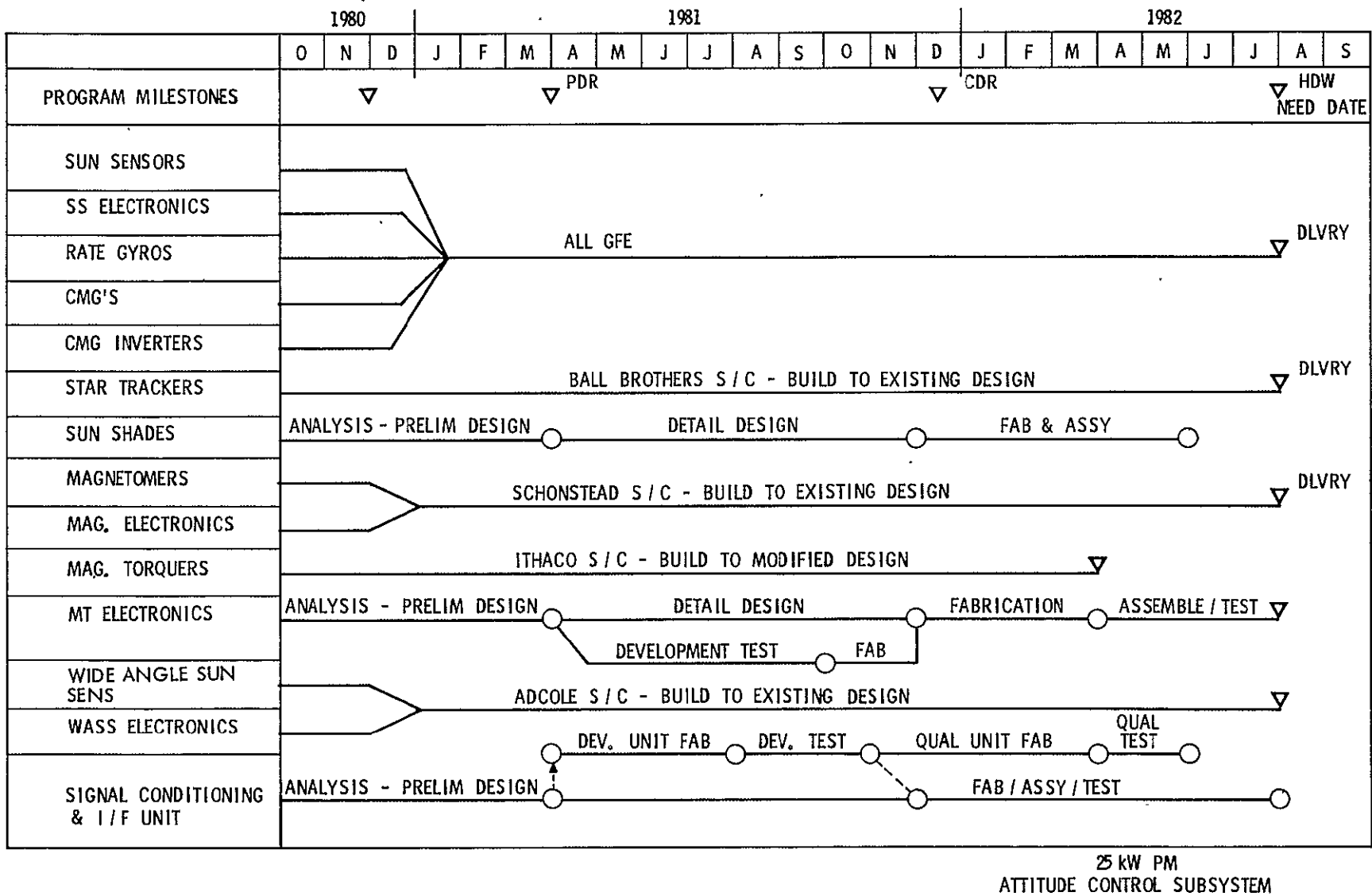


Figure 3-5 Attitude Pointing and Control Subsystem Development Network

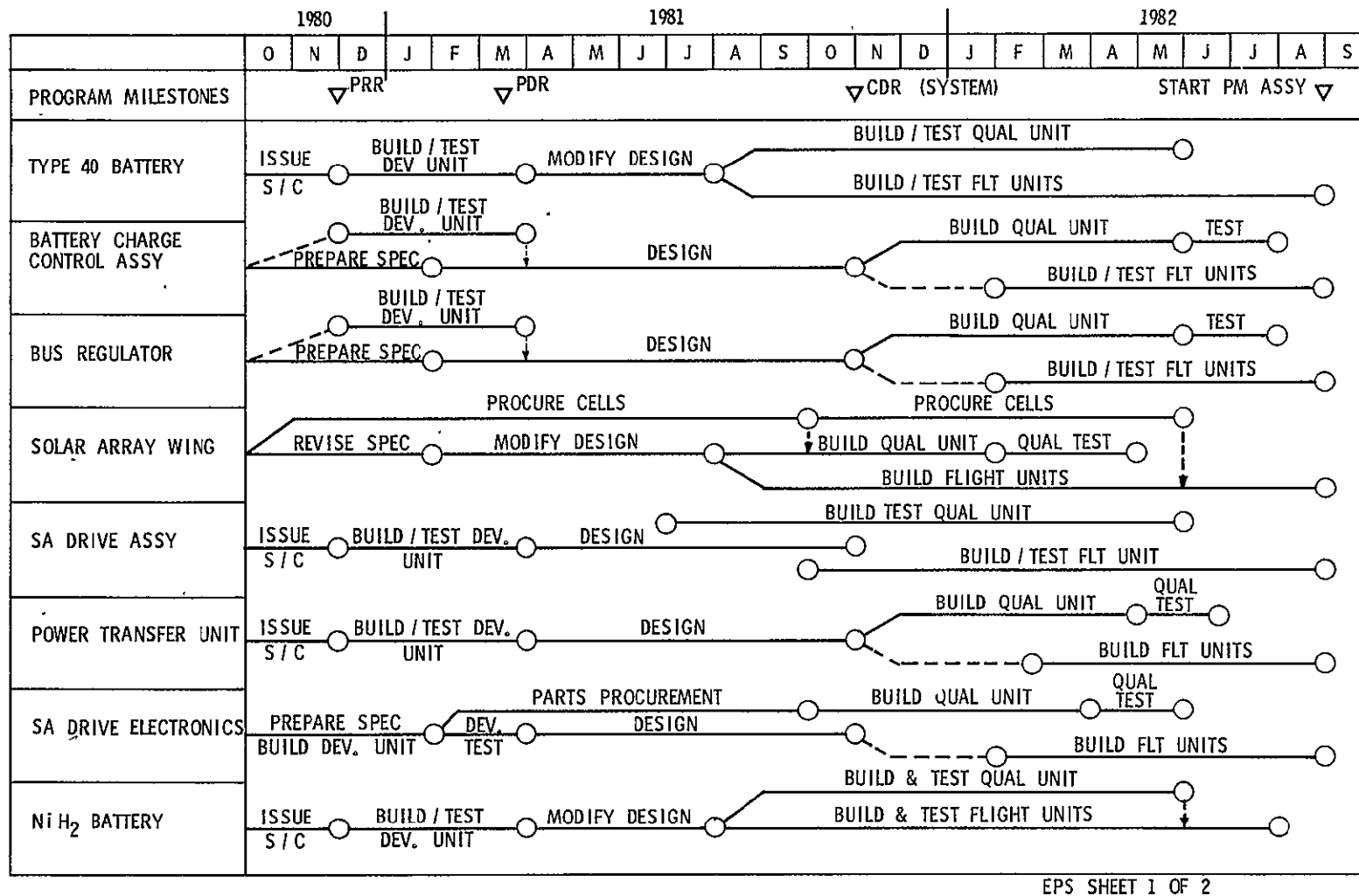
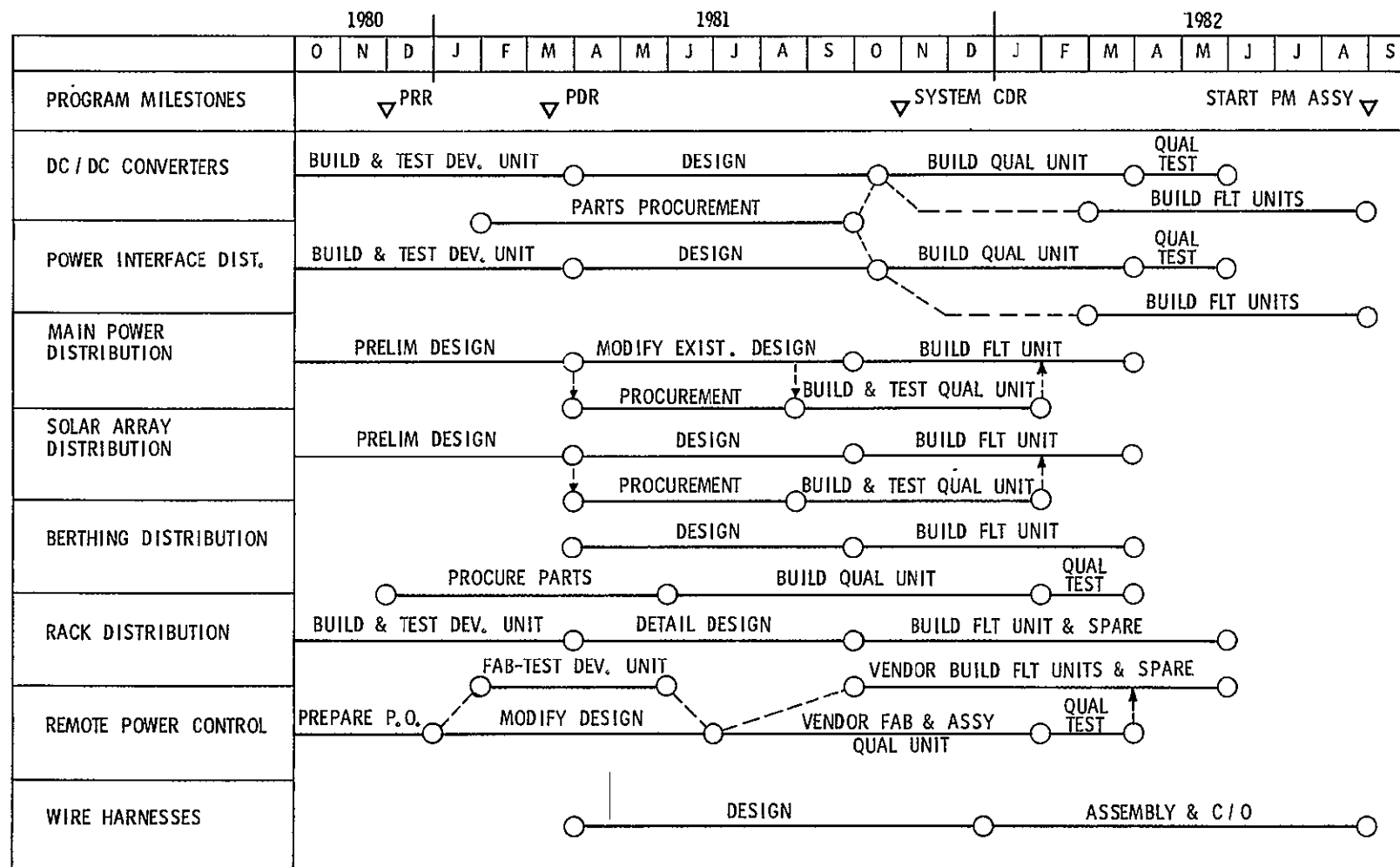


Figure 3-6 Electrical Power Subsystem Development Network



EPS SHEET 2 OF 2

Figure 3-6 Electrical Power Subsystem Development Network (Continued)

LMSC/D614944-2

Figure 3-8 presents a tentative schedule for development of the first 50 kW Power Module. The critical path follows the solar cell production panel fabrication and wing assembly activities. Based upon manufacturing processes, assembly and testing techniques fully proven on the 25 kW Power Module, no significant schedule risks are evident and a 30 month span from go-ahead to launch appears practical.

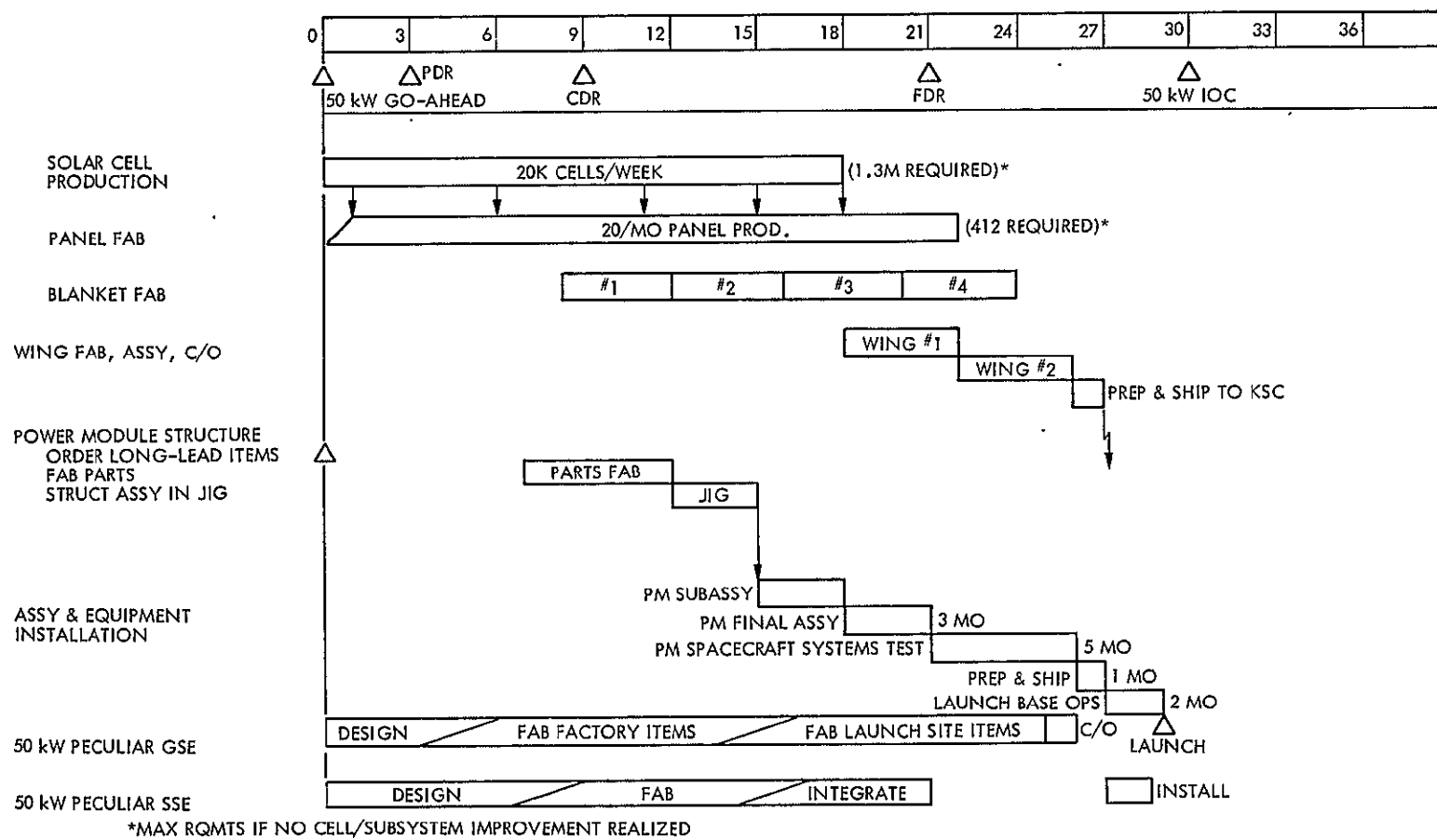


Figure 3-8 50 kW Power Module Development Schedule

Section 4

PROGRAM TEST PLANS

4.1 TEST PHILOSOPHY

The 25 kW Power Module will use existing off the shelf components to a large extent. The test program, therefore, merges the use of existing, qualified items with new design items into a cost effective test program. Highlights of the test philosophy are:

- a. Perform minimum of ground tests.
- b. Minimize program cost.
- c. Greater risk is acceptable since shuttle recovery capability permits return to earth.
- d. Maximize testing at lower levels of assembly.
- e. Qualify by analysis if possible (emphasis on all existing design).
- f. Minimum subsystem testing at launch site ("Ship and Shoot" concept).

Testing guidelines to be applied to the program are:

- a. All components and parts which cannot be certified as flight qualified hardware by similarity shall undergo qualification tests and then only to the extent necessary to certify as flight qualified.
- b. During final assembly, continuity tests shall be accomplished on all electrical systems. All cables should have continuity tests after installation, but before final connection. All fluid systems shall be leak checked prior to acceptance of a system.
- c. Thermal vacuum qualification tests shall be performed on the Thermal Control Subsystem.
- d. An all systems acoustic test shall be performed at the factory to verify PM systems performance.

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- e. A post transport systems test should be performed at the launch site to ensure that the PM has withstood transportation loads without suffering any damage. Final assembly of all PM components (array, ordance, flight batteries, etc.) will be accomplished in the payload processing facility at KSC. All non-flight hardware is removed and the active TCS fluid level is checked at this point. No other testing or work should be planned for this location to minimize ground support equipment.
- f. Before installation in the Orbiter all PM electrical and mechanical interfaces shall be verified in the Cargo Integration Test Equipment (CITE) facility at the O&C Building.
- g. SSE shall be installed in the orbiter at the Orbiter Processing Facility. All SSE interfaces shall be verified after installation.
- h. The PM shall be loaded onboard the Orbiter in the horizontal attitude at the Orbiter Processing Facility. All PM/Orbiter mechanical and electrical interfaces shall be verified after installation.
- i. During the Orbiter readiness test on the launch pad, all PM/Orbiter electrical interfaces shall be verified. The PM is then certified as ready to support launch operations. The CMGs shall be maintained in a slow spin mode and the batteries may require trickle charge support.

4.2 TEST CONCEPTS

Test concepts for the various test requirements are presented below:

Development Test Requirements

Test Concepts

- a. Component qualification test

All new, repackaged or modified components shall undergo qualification certification.

Development Test Requirements

Test Concepts

b. Modal tests on Power Module Structure

All up structure-vertical mounted. Force excitation and response survey using computer techniques.

Equipment simulators shall be used for mass simulation. Solar Array panels shall be simulated in nonflight canisters in the launch (stowed) configuration.

c. Assembly - continuity tests/leak tests

All systems, including cables shall be tested for continuity and fluid systems shall be checked for leaks during final assembly.

d. Assembly - system functional tests

Ambient only on all systems using interface simulation for shuttle, solar array, batteries.

e. Thermal vacuum (TV) tests

Subsystem level if possible; overall TV not necessary

f. Acoustic test

Perform an all systems acoustic test

Launchsite Test Requirements

- | | |
|---|---|
| a. PM pre-launch preparation | Install batteries and solar arrays - Perform an all-system electro-mechanical test at ambient conditions after transport to KSC. |
| b. PM-Orbiter pre-installation interface verification | Test in CITE at the O&C bldg. |
| c. SSE preparation and verification | Prepare SSE and verify by continuity and functional tests in O&C bldg. |
| d. SSE installation in Orbiter | Install SSE in Orbiter at the OPF. Verify Orbiter/SSE interfaces after installation. |
| e. PM Installation in Orbiter and post-installation interface verification. | Prepare and install the PM into the Orbiter payload bay at the Orbiter Processing Facility. Perform visual and functional signal interface verification after installation. |
| f. PM prelaunch readiness | On launch pad, verify Orbiter-PM interfaces. Verify PM status. Execute low speed spin up of CMGs (1000 rpm). |

4.3 POWER MODULE TEST FLOW SEQUENCE

The flight vehicle shall be assembled at a contractor facility and tested as a complete assembly before shipment to the launch site (KSC). The solar array subsystem including drive control assembly and extend/retract mechanism shall be tested. Fit checks will be performed with the core PM using templates. S/A simulators, radiator simulators and battery simulators shall be used during PM environmental tests. Test program flow sequences are shown in Figure 4-1 for the Power Module and in Figure 4-2 for the Power Module on orbit growth kit.

4.4 DEVELOPMENT TEST PLANS

Definitive test plans will be prepared during Phase B based upon the specific design concepts and hardware selection produced at that time.

4.5 OPERATIONAL TEST PLANS

The Power Module System verification activities are shown in this Figure 4-3. Predeployment, deployment, and PM verification checkout can be performed in one day.

Demonstration of Orbiter/PM sortie mode operations is estimated to require two days. During this time active interfaces with PM electrical power subsystem, thermal control subsystem, and attitude control subsystem shall be exercised in various orientation modes to demonstrate system capability. Communication interfaces and procedures between the Orbiter Ground Operations Control Center and the PM Operations Control Center will be demonstrated.

A key aspect of the PM free-flyer demonstration will be to verify the capability of the PM Operations Control Center to control and monitor the PM flight operations. These activities are estimated to require three days.

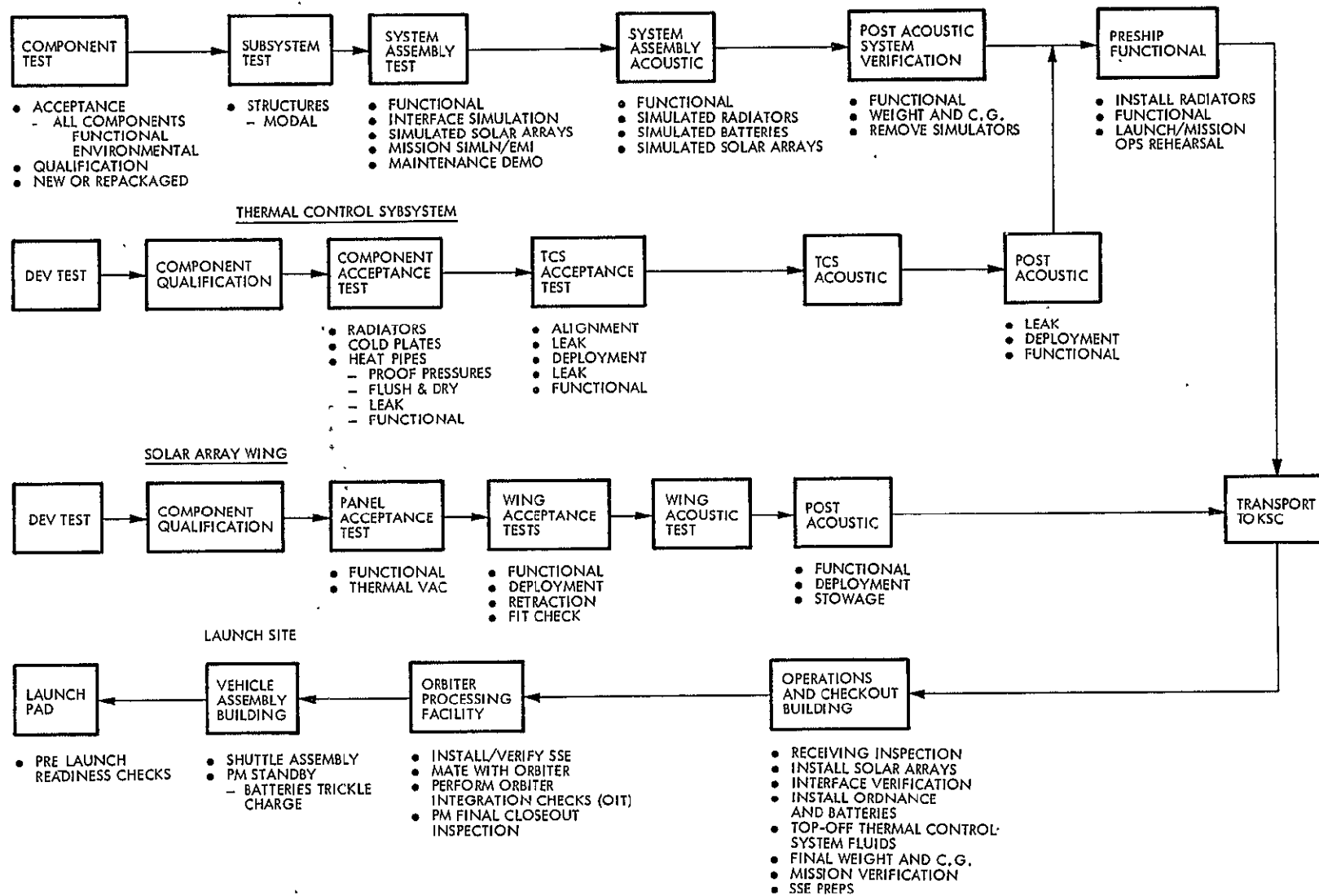


Figure 4-1 25 kW Power Module Ground Test Program

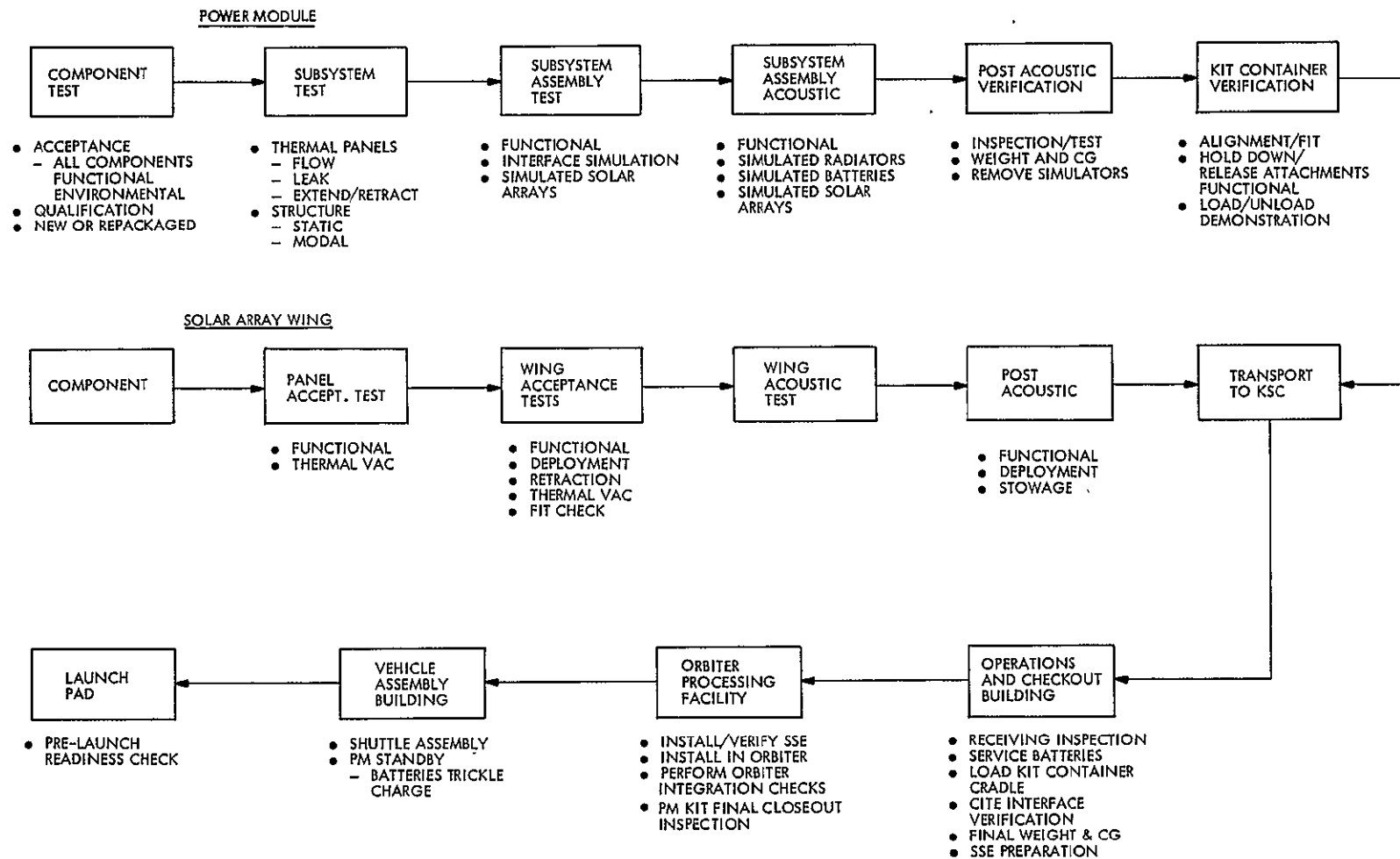


Figure 4-2 50 kW Power Module Growth Kit Ground Test Program

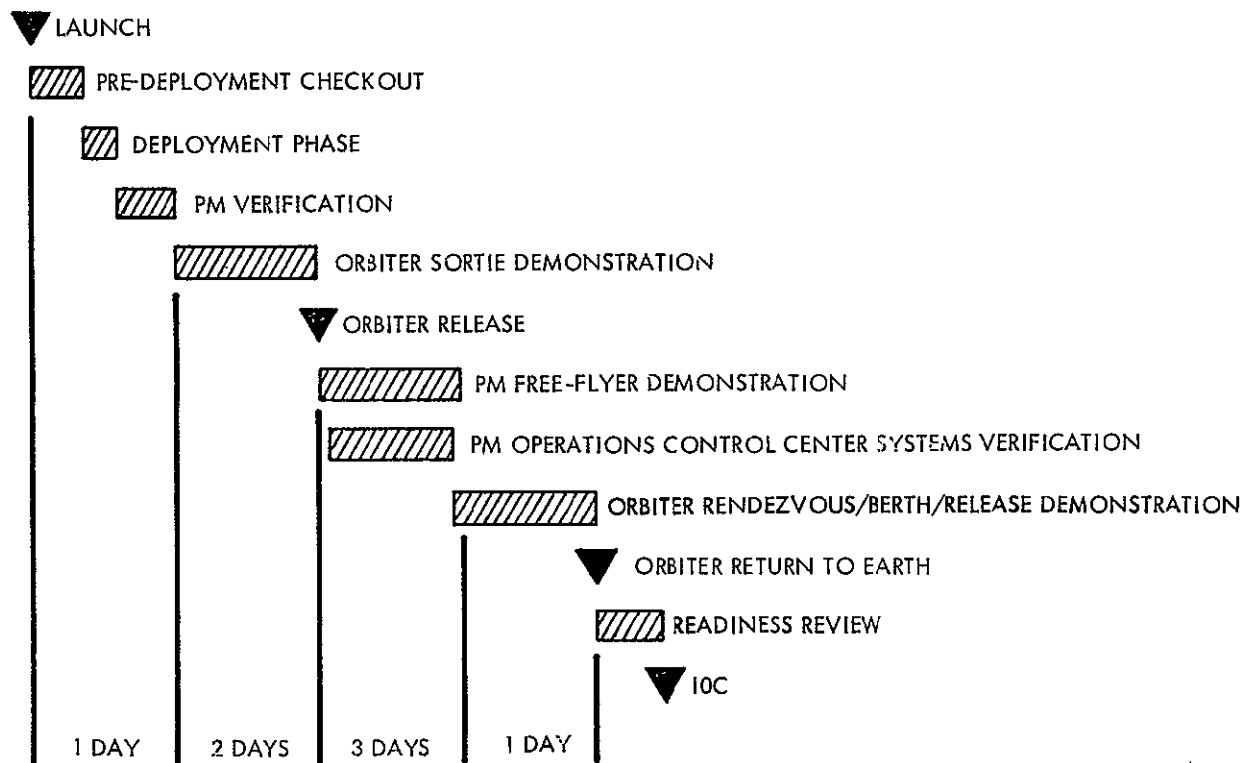


Figure 4-3 Verification Mission Activities

Capabilities of the Orbiter to rendezvous with the free-flying PM will be demonstrated. The Orbiter shall then demonstrate capability to precondition the PM for berthing by commanding retraction of solar arrays, thermal radiators, and positioning of antennas. Recapture by the TMS will be executed, followed by a berthing and subsequent release demonstration. These operations are estimated to require one day. The Orbiter will then return to earth following this seven day Verification Mission.

Section 5

PROGRAM OPERATING CONCEPTS AND PLANS

The 25 kW Power Module program for operations has two areas of concern, ground and flight (orbital) operations. Ground operations must be compatible with the Shuttle Space Transportation System and emphasize pre-launch/launch preparation, ground support for flight operations and refurbishment.

Flight operations must be compatible with Shuttle planned procedures and performance capability and emphasize orbital deployment/berthing, maintenance and growth operations with the supporting logistics.

5.1 GROUND OPERATIONS

Ground operations activity centers around the preparation of Power Module vehicles for launch at Kennedy Space Center (KSC). In addition, Power Module space support equipment is serviced and installed in the Orbiter to directly interface and support the Power Module during launch/delivery/placement, sortie and payload delivery/revisit flight modes.

Major ground operations will focus on processing of the flight vehicles. There are nine vehicles scheduled for processing during the 1983-1991 period, per Scenario I. Of the nine, eight are placement flights and one is a growth kit addition flight. Activities for flight vehicles and kits will include prelaunch preparation and checkout of the vehicles/kits and then installation/integration in the Orbiter vehicle. Space support equipment (SSE) will be integrated in to the Orbiter before launch and removed after landing return of the Orbiter.

For a recovery return flight, both SSE and the Power Module/elements will be removed after landing return of the Orbiter.

The primary support for Orbiter sortie and payload addition/removal flights will be to install the SSE and pallets in the Orbiter before launch and to remove the SSE and pallets from the Orbiter after landing return.

The ground operations flow sequence for the Power Module interfaces with the STS processing facilities and orbiter vehicle are shown in Figure 5-1. All processing times for the PM are within Orbiter processing timelines. To accommodate the PM size, the NASA Guppy aircraft is used to transport the vehicle from the factory to the KSC landing site. Upon arrival the PM is transported via ground carrier to the Operations and Checkout building where the vehicle will be prepared for flight. The PM will be processed in a horizontal attitude and will conform to the O & C processing flow line. The solar array containment cannisters and battery pack modules will be installed into the PM vehicle and tests will be performed to verify PM subsystems and interfaces. For a final verification of the PM/Orbiter interfaces, the PM will be tested in the cargo integration test equipment (CITE). The tests will verify the readiness of the PM to be installed in the Orbiter. The PM will be placed in the payload cannister and transported to the Orbiter Processing Facility for horizontal installation in the Orbiter cargo bay where PM space support equipment will have previously been installed and tested.

The PM remains inactive at the Vertical Assembly Building during Shuttle build-up activities. At the launch pad the PM will be activated to verify functional interfaces with the Orbiter and verify launch readiness. Prior to launch the batteries may be "trickle" charged (TBD) and the control moment gyros will be spun up to low speed for launch.

The following paragraphs discuss Launch Preparation/schedules, Orbital Operations Ground Support and Refurbishment.

5.1.1 Launch Preparation and Support Plans/Schedules

Launch preparation and prelaunch operations are shown in Figure 5-2. At the KSC launch site the PM assembly sequence and prelaunch operations are oriented toward processing the vehicle in a horizontal attitude in the Operation and Checkout (O & C) Building. Assembly activities on the PM include the following:

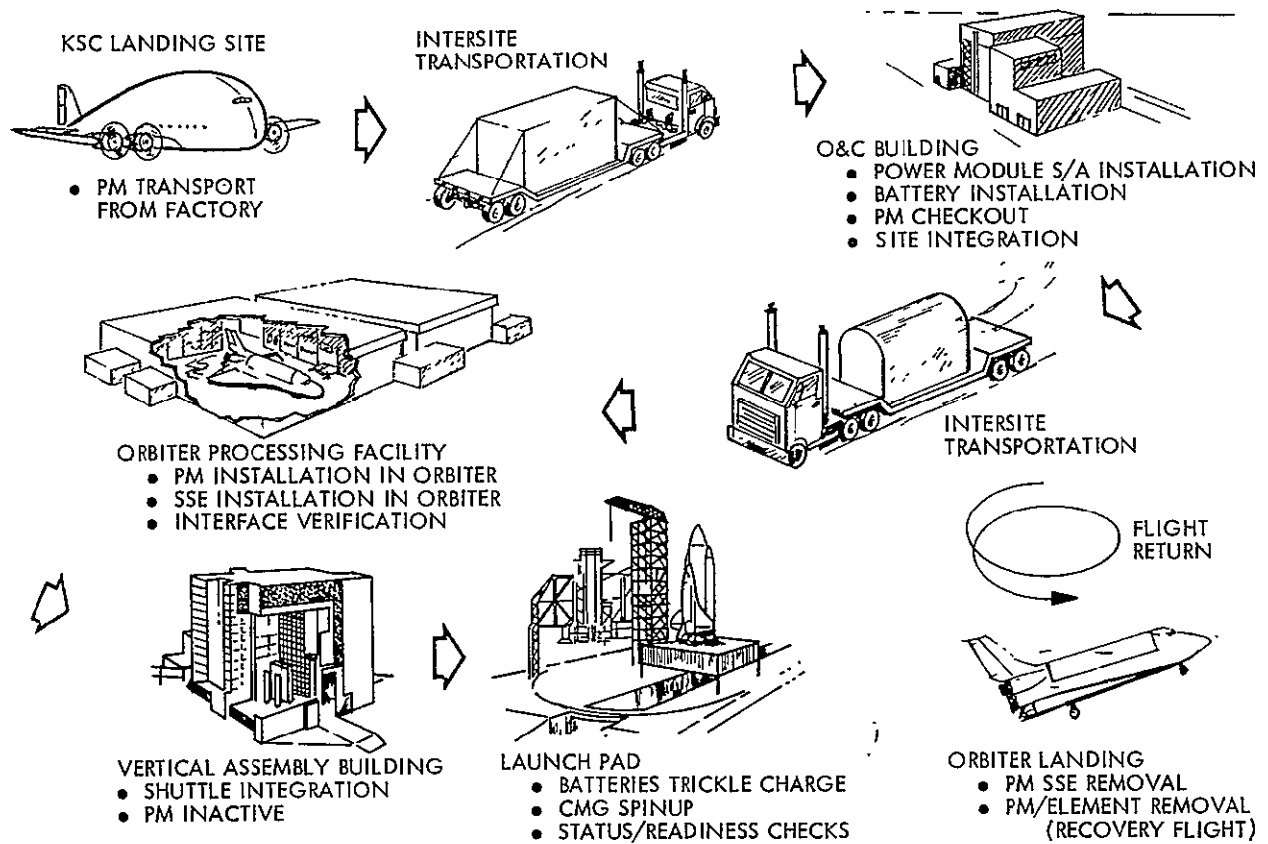


Figure 5-1 Power Module Ground Operations

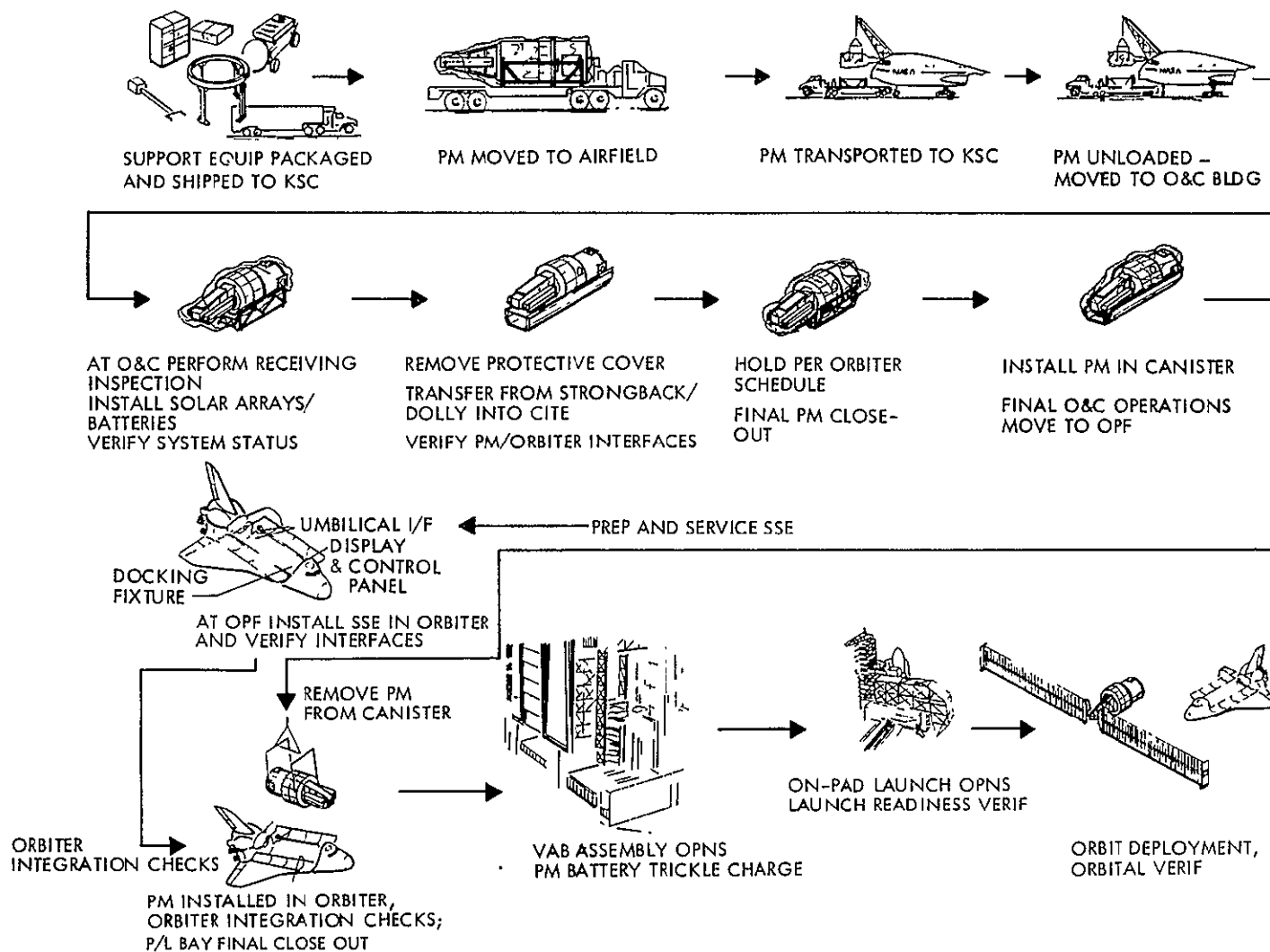


Figure 5-2 Power Module Assembly Verification Sequence - Launch Site

- Installation of solar array wing assemblies
- Charging and installation of the flight batteries
- Installation of PM space support equipment in the orbiter at the Orbiter Processing Facility.

Space support equipment for the PM/Orbiter interfaces will be serviced, updated, and maintained in the O&C building. Before installation in the Orbiter the SSE will be verified by performing signal continuity and functional testing. SSE will be installed in the Orbiter at the OPF to support Orbiter/PM operations. After the equipment is installed in the Orbiter, verification tests of the Orbiter/SSE interface compatibility shall be conducted.

After return from orbit flight, the SSE will be removed from the Orbiter at the OPF. The SSE will be returned to the O&C building for inspection, testing, and updating as required to support subsequent PM/Orbiter flight operations. Reverification of the SSE will be performed for every succeeding flight using signal continuity, visual inspection, and functional testing techniques. Interface simulators may be used as needed to represent both Orbiter and PM interfaces during this functional testing.

The PM will be installed in the Orbiter at the OPF and will remain in the payload bay during all subsequent shuttle assembly operations. The only unique requirement for PM support while in the Orbiter may be the maintenance of a trickle charge on the PM batteries. (To be determined)

Verification tests will be performed during the processing sequence as follows:

- Visual inspection of flight hardware and review of records on receipt of equipment at the launch site.
- Solar array continuity test after installation on the PM.
- Battery performance tests including charge and discharging testing after installation in the PM.
- PM systems functional performance tests.

- Interface verification of the PM/Orbiter interface using the cargo integration test equipment in the O & C Building.
- Integration checks of Orbiter/PM functional interfaces after PM installation in the Orbiter.
- Pre-launch PM system status verification tests on the launch pad.

The 25 kW PM launch processing timeline is shown in Figure 5-3. All shuttle times are from STAR reference 5.

Major timeline activities are associated with processing of the PM at the Operation and Checkout (O & C) Building. These activities are independent of the Orbiter processing and require approximately 15 operational days (3 weeks).

Interface with the Orbiters on line processing begins in the Orbiter Processing Facility (OPF) with the installation of PM space support equipment at approximately 130 hours before launch.

Actual installation of the Power Module in the Orbiter Cargo Bay is planned to be performed at the OPF approximately 90 hours before launch. After installation in the Orbiter Cargo Bay, the PM will remain essentially quiescent during Orbiter preparation of the Vertical Assembly Building (VAB) and the launch pad.

Years 1984, 85, 87 have no scheduled launches and years 1986, 87 have two scheduled launches each. With this relatively low launch rate, it is reasonable and cost effective to propose an "Augmented team" concept for the purpose of providing for the power module launch support.

Results of a personnel requirements evaluation are shown in Table 5-1. A resident staff at the launch site (KSC) will handle ground operations processing for growth kits, PM networks, and installing/removing SSE for Shuttle sortie missions. When a Power Module is being processed for launch the resident staff will be augmented by a "travelling team" complement from the factory.

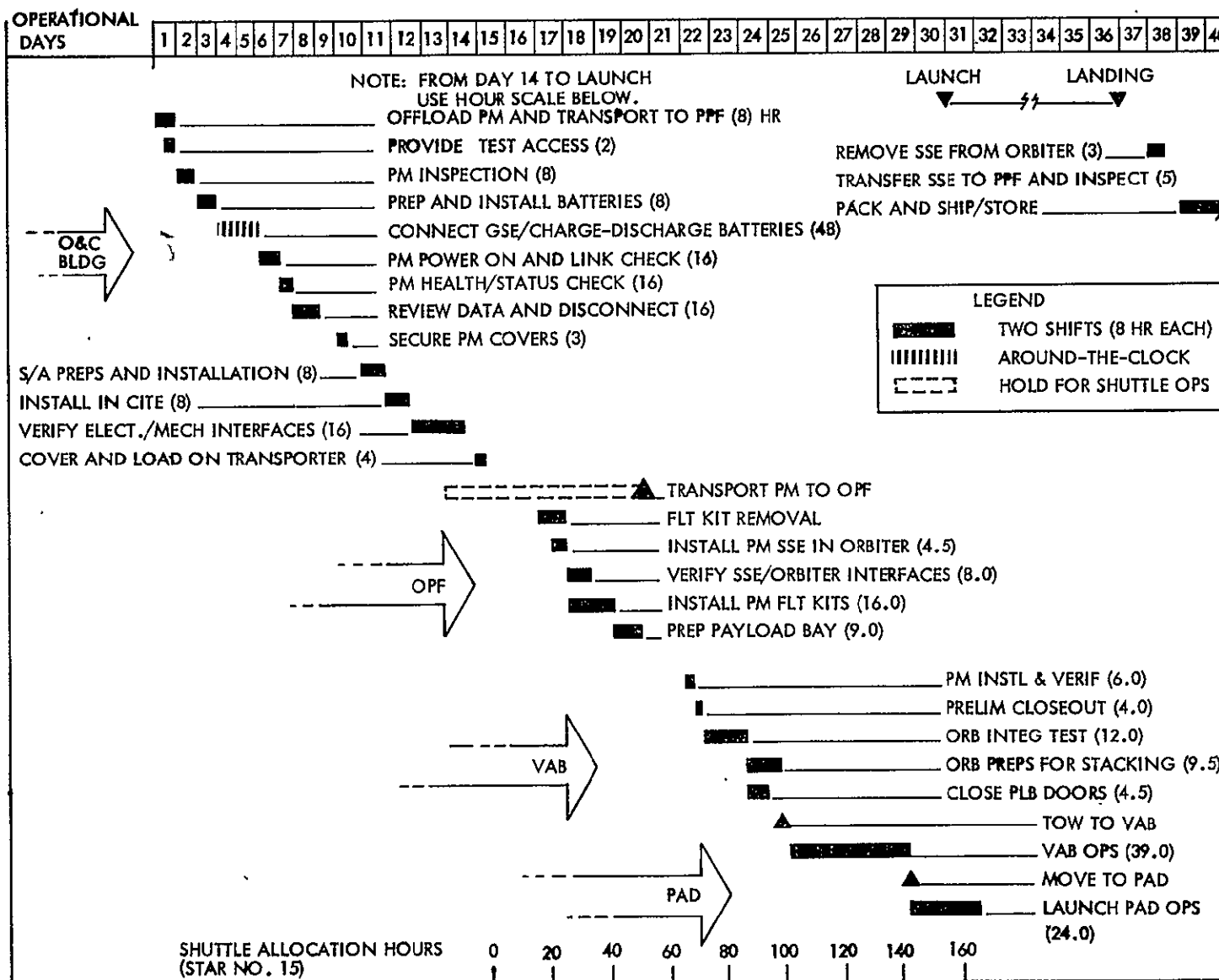


Figure 5-3 Power Module KSC Processing Timeline

TABLE 5-1
PM/KSC PERSONNEL REQUIREMENTS EVALUATION

- POWER MODULE LAUNCH OPERATION
 - WORST CASE PERSONNEL REQUIREMENT
 - RESIDENT STAFF SUPPLEMENTED BY TRAVELING TEAM
- GROWTH KIT LAUNCH OPERATION
 - RESIDENT STAFF ONLY
- POWER MODULE RETRIEVAL OPERATION
 - RESIDENT STAFF ONLY
- SORTIE OPERATIONS - SSE INSTALLATION/REMOVAL
 - RESIDENT STAFF ONLY
- RESIDENT STAFF COMPLEMENT
 - RESIDENT SUPERIVSOR/TEST CONDUCTOR (1)
 - SECRETARY (1)
 - PLANNER/COORDINATOR (1)
 - MECHANICAL ENGINEER (1)
 - ELECTRICAL ENGINEER (1)
 - MECHANICAL TECHNICIAN (2)
 - ELECTRICAL TECHNICIAN (2)
 - INSPECTOR (2)
 - COMPUTER/SOFTWARE PLANNING ANALYSES (2)
 - MISCELLANEOUS (3)
- TRAVELING TEAM COMPLEMENT (1)
 - TEAM LEADER/ASSISTANT TEST CONDUCTOR (1)
 - GUIDANCE ENGINEER (2)
 - ELECTRICAL ENGINEER (1)
 - TELEMETRY ENGINEER (2)
 - THERMAL ENGINEER (1)
 - MECHANICAL TECHNICIAN (2)

TABLE 5-1 (Continued)

o	ELECTRICAL TECHNICIAN	(2)
o	INSPECTION SUPERVISOR/MATERIAL REVIEW LIAISON	(1)
o	COMPUTER/SOFTWARE	(2)
o	MISCELLANEOUS	(5)

5.1.2 Orbital Operations Ground Support

Orbital ground support requirements are defined by the Power Module mission phases. Seven different flight operating modes are depicted indicating the major flight performance functions and operating interfaces. Operational elements of the Space Transportation System, communications links with the TDRS network, and Orbiter, Power Module, and payload ground control centers will be required to support these mission phases as shown. During those flights when the Orbiter is involved (PM placement and verification, Orbiter sortie, PM maintenance/growth and PM recovery), primary mission control is under Shuttle authority. Communications and command control shall be exercised by the Shuttle Mission Control Center (MCC) at the Johnson Space Center. For PM ground control it is assumed that a Power Module Operations Control Center (PMOCC) will be operating and supportive to the MCC. A Payload Operations Control Center (POCC) may be supporting the MCC depending on the complement of the flight payloads.

When the PM is operating in the Free-Flyer Orbit storage (inactive) mode, it is assumed that command and control functions will be directed through a PMOCC. General status and flight performance/planning data for the PM will be furnished to Shuttle MCC and the Goddard Space Flight Center POCC as required.

In the active free-flyer mode, the PM provides support to attached payloads. For this case it is assumed that direct PM operations are controlled by the PMOCC. Control of attached payloads will be the responsibility of the POCC working through the PMOCC.

The Power Module Operations Control Center (PMOCC) houses the personnel responsible for PM mission planning, command and control, telemetry monitoring, data processing and PM subsystem analysis. PM operations will have two operational areas of responsibility GSFC and JSC. During Free-Flyer orbit storage (inactive mode) and Free-Flyer Payload Support it is assumed command and control will be at GSFC without JSC involvement.

During the Orbiter PM manned modes (sorties support, on-orbit growth/maintenance/recovery) JSC will exercise primary mission control and will require PM support with the appropriate console allotment.

The PMOCC will be established as an operations element responsible for all PM inflight operations; including orbital verification, in-flight mission periods while associated with the Shuttle Orbiter, deployment, on-orbit servicing, retrieval/recovery and mission operations. PMOCC mission operations will be conducted 7 days a week, 24 hours per day.

The primary functions to be performed by the PMOCC are:

- o Mission Planning/scheduling - STS and P/L interface (long range, near and real time)
- o Commanding - PM attitude control, PM Conditioning (on/off switching functions, retract/extend solar arrays, radiators).
- o Analysis - Telemetry (PM subsystem status), flight performance-trajectory analysis
- o Testing/simulation-launch, on-orbit, recovery and anomalies
- o Ground support communications and data flow

To accomplish these mission functions the following operational personnel will be required:

PM MISSION OPERATOR - Technical and administrative responsibility for PMOCC operations. Primary interface for implementing STS and P/L integration. He is the shift supervisor.

1 per shift Total 3

PM MISSION PLANNER/SCHEDULER - Implements PM mission operations and maintains long range schedules. Prepares and checks inputs to daily/weekly operations

plans. Ensures log is maintained of completed operations. Has thorough knowledge of Orbiter requirements.

1 per shift Total 3

PM ANALYST - Responsible for maintaining a thorough knowledge of PM subsystems and evaluating telemetry data. Reviews data records of PM configuration, power expenditure and subsystem performance. Monitors and implements pre-programmed and real time commands.

1 per shift Total 3

DATA CONTROLLER - Coordinates data transmission with TDRS/STDN ground stations. Operates data handling equipment in the control center and monitors incoming/outgoing data using appropriate hardware. (line printers, etc.)

1 per shift Total 3

SOFTWARE ANALYST - Has overall technical responsibility for the operation and maintenance of PMOCC software. Tests the functions of software, resolves software anomalies and develops operating procedures. Responsible for testing and simulation when required.

1 per shift Total 1

MAINTENANCE TECHNICIAN - Operates and maintains displays, plotters, etc. and test equipment as necessary to support normal operations. Performs regular equipment preventive maintenance checks and maintains complete maintenance records.

2 shifts Total 2

The personnel described (15) are those required to operate the PMOCC on a 24 hour basis and does not include support personnel (data clerk, computer operators, etc.).

Thorough analysis must be performed in Phase B to determine definitive position descriptions, skill levels, total manning and equipment requirements.

5.1.3 Refurbishment

The philosophy utilized for refurbishment is to minimize disassembly and use flight data to establish rework/replacement. Inspection will be for cleanliness and damage with testing at the highest assembly level (ambient only).

The nominal refurbishment concept is to:

- o Perform inspection & assessment
- o Replace operating life items
 - Batteries
- o Replace discrepant items
- o Clean surfaces/sensor elements
- o Perform critical component acceptance/confidence tests
 - CMGs
 - Computer
 - Power transfer equipment
- o Perform ambient system tests

Factors considered are that the 25 kW PM will be in orbit for 30 months and must be reconditioned for another 5 year life with the same capability. The PM will be returned to the factory for refurbishment. The action to be taken during refurbishment are as follows:

- | | | |
|----------------------|---|-----------------------------|
| Structures | o | Inspection-visual/NDT |
| | o | Decontaminate and clean |
| | o | Alignment check |
| Thermal. | o | Visual inspection |
| | o | Drain/replace cooling fluid |
| | o | Leak check |

ACS	o	Visual inspection
	o	Clean sensor optics
	o	Subsystem test ambient
C & DH	o	Visual inspection
	o	Subsystem Test ambient
Power	o	Visual inspection/extended arrays/panel tests
	o	Service drive assembly
	o	Power control subsystem test
	o	Replace batteries, distributors, wiring
PM System	o	Ambient systems functional test

A typical Power Module refurbishment sequence and timeline is shown in Figure 5-4. This sequence is oriented to the test program discussed in the next paragraph and shows a relatively rapid rework/turnaround capability.

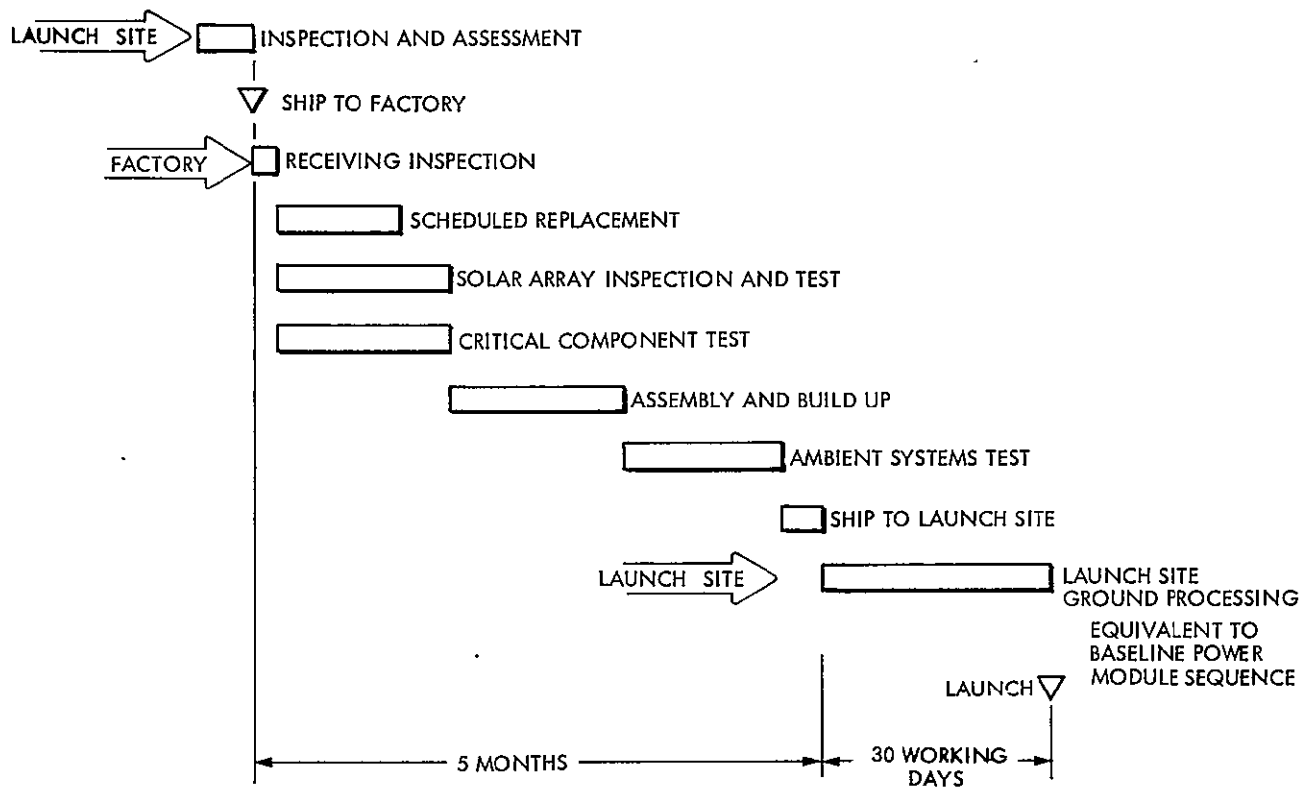


Figure 5-4. PM Ground Refurbishment Sequence

The five months allocated at the factory is estimated as realistically achievable in the 1986-1988 time period since this will be four years into the PM program. The thirty operational days at the launch site is identical to the time span for processing of the first flight vehicle.

The objective of refurbishment will be to recondition the vehicles to a capability for a five-year orbit life. Refurbishment will be conducted at the factory to make use of the component and subsystems assembly and test capability which will exist there.

The refurbishment philosophy will be to minimize disassembly and to use flight performance records, visual inspection, and initial evaluation testing to establish rework/replacement requirements. After return flight in the Orbiter, the PM will be removed from the payload bay in the Orbiter processing facility and transported to the Operations and Checkout building for inspection. The solar arrays and battery modules will be removed and the PM, solar arrays, and battery elements will be shipped to the factory via air carrier (Guppy). At the factory, a systems functional evaluation test will be performed on the PM and a subsystem functional evaluation test will be performed on the solar arrays. Subsystem components will be replaced as required. Subsystem and system tests will be performed and a system assembly acoustic test of the PM will be conducted utilizing simulators for solar arrays, batteries, and radiators. Final acceptance of the refurbished PM at the factory will include an all-systems sequenced mission simulation test. With successful completion of these tests at the factory, the flight equipment will be considered "ready for flight".

Ground operations processing at the launch site will be identical to the sequence and operations used for an initial PM placement flight. The refurbished vehicle will be prepared at the Operation and Checkout building. Space support equipment and the PM will be installed in the Orbiter at the Orbiter Processing Facility and prelaunch readiness checks will be performed at the launch pad.

5.2 ORBITAL OPERATIONS

The Power Module flight operations consist of two major phases. Phase I is the initial placement Verification Mission leading to IOC. Phase II will consist of operational payload support missions. Figure 5-5 illustrates the two phases.

The objective of Phase I is to demonstrate capabilities of the PM system to operate in conjunction with the Orbiter vehicle and as a free-flyer vehicle. The shuttle will transport the PM to low earth orbit (235 nm). Using the Orbiter remote manipulator system (RMS), the PM will be removed from the cargo bay and positioned and berthed to the Orbiter vehicle. All functional capabilities of the PM will be demonstrated for sortie mode operations with the Orbiter. Following successful performance verification, the PM will be separated from the Orbiter and will be operated in a free-flyer mode to demonstrate all systems performance. Following these successful operations the PM will be conditioned for on-orbit storage. The shuttle Orbiter will return to earth.

Following a review and favorable assessment of the PM demonstration, the PM will have attained IOC status, and Phase II flight mission operations will begin.

Phase II will consist of operational payload support missions. These will be conducted in both Orbiter sortie mode and in the free-flying mode. The Orbiter will perform rendezvous and berth with the PM for sortie mode missions. For free-flyer missions, the Orbiter will transfer payloads and through EVA, attach and recover payloads from the PM. Maintenance will be performed on the PM in orbit by Orbiter berthing and astronaut EVA activities.

The major areas in orbital operations are:

- o Orbital Deployment/Berthing Operations
- o Orbital Maintenance Operations

INITIAL FLIGHT DEMONSTRATION POWER MODULE SYSTEMS

- DEPLOYMENT
- RETRIEVAL
- DOCKING
- BERTHING
- SORTIE MODE
- FREE-FLYER MODE
- ORBIT STORAGE MODE
- COMMUNICATIONS

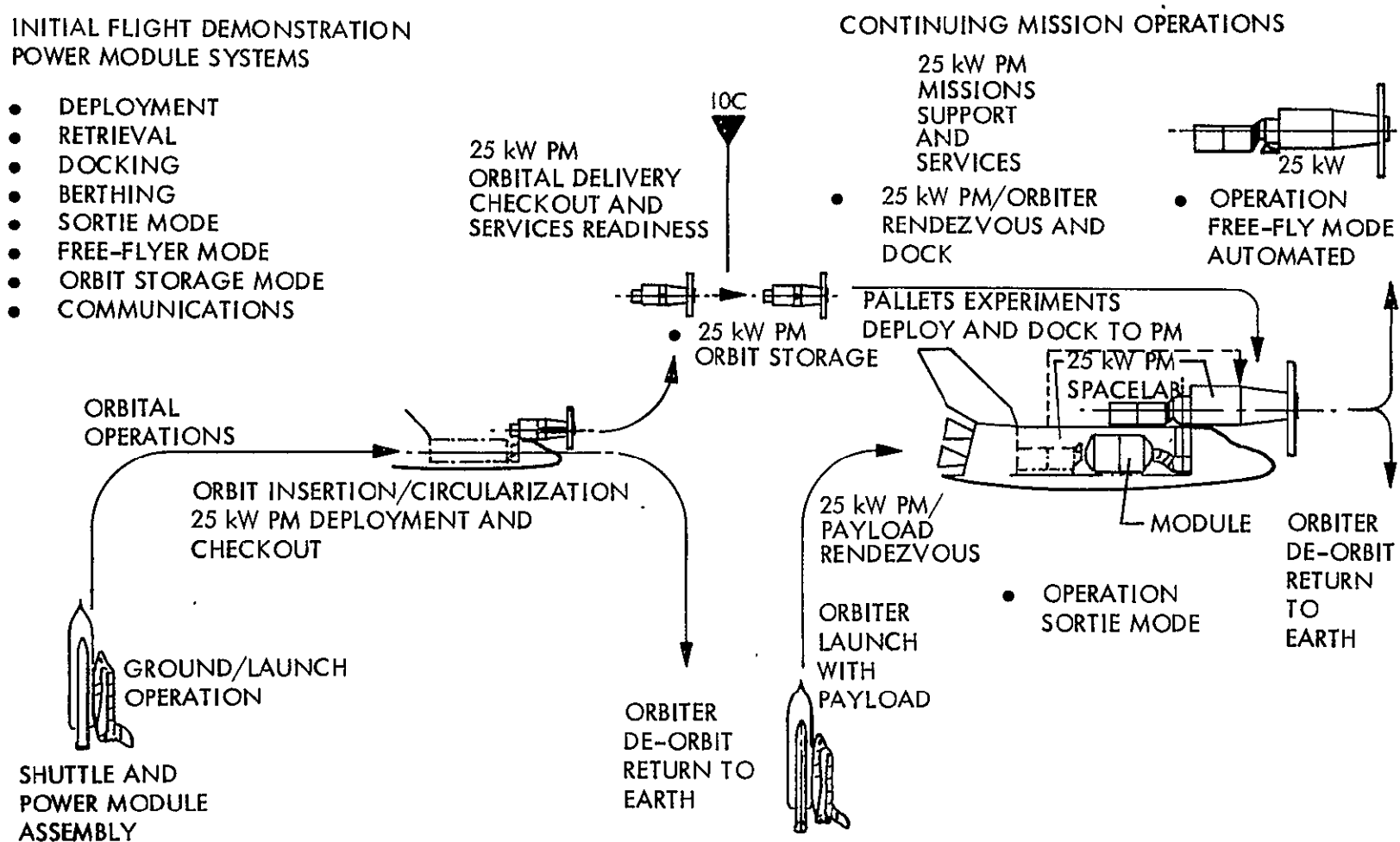


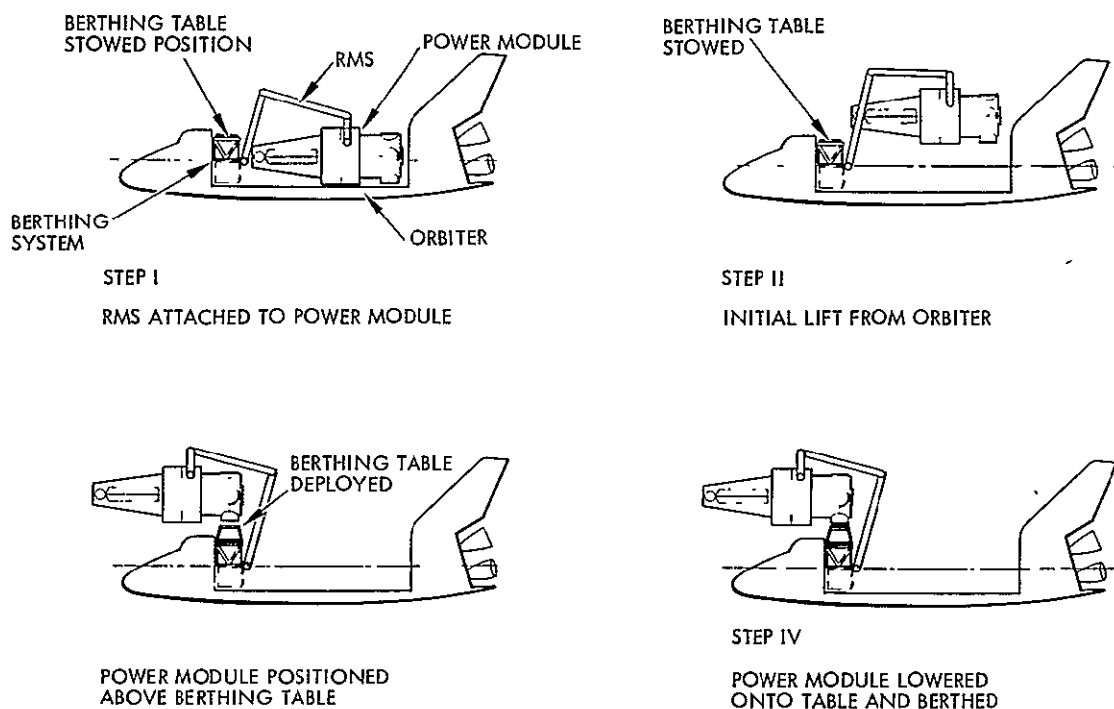
Figure 5-5 25 kW Power Module Flight Operation

- o Orbital Growth Operations
- o Logistics

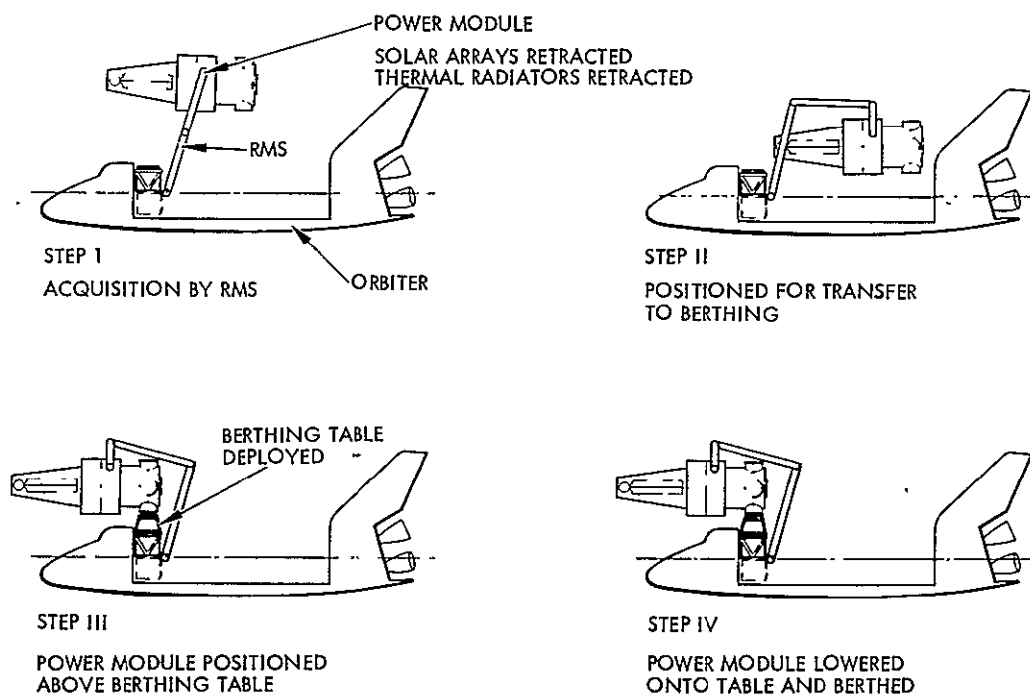
5.2.1 Orbital Deployment/Berthing Operations

There are four flight orientation sequences performed during deployment/berthing operations. Figure 5-6 illustrates the Deployment/ Berthing Sequence and On-Orbit Capture/Berthing Sequence. Figure 5-7 illustrates the On-Orbit Maintenance sequence and On-Orbit Recovery sequence. All these sequences require one RMS and a berthing table to perform the grappling, translation, and tiedown activities.

For the recovery sequence, however, the berthing table is not required since the Power Module is transferred directly into the Orbiter Cargo Bay without berthing.

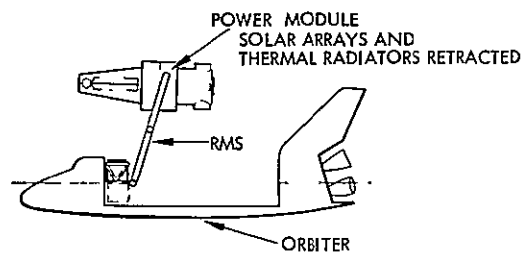


DEPLOYMENT/BERTHING SEQUENCE

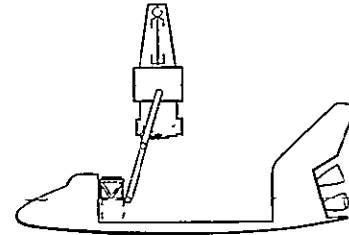


ORBIT CAPTURE/BERTHING SEQUENCE

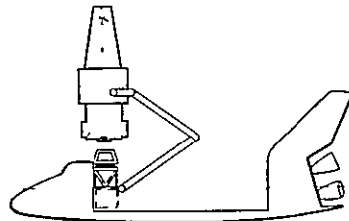
Figure 5-6 Initial Deployment/Berthing Sequence



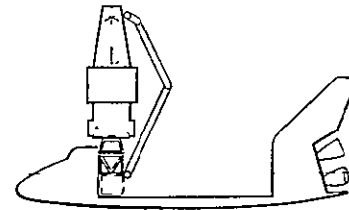
STEP I
ACQUISITION BY RMS



STEP II
POWER MODULE ROTATED

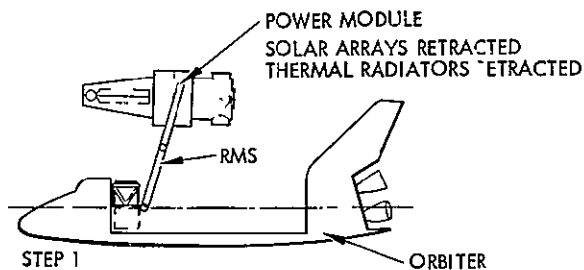


STEP III
POWER MODULE TRANSLATED FORWARD
ABOVE BERTHING TABLE.
BERTHING TABLE EXTENDED.

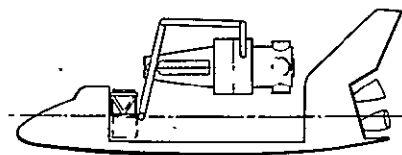


STEP IV
POWER MODULE BERTHED
MAINTENANCE PLATFORM & ACCESS
MAST EXTENDED

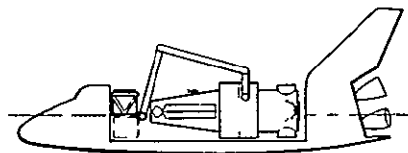
ORBIT MAINTENANCE SEQUENCE



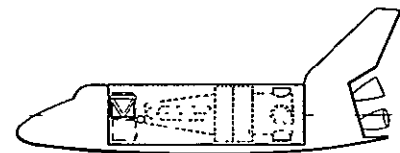
STEP I
ACQUISITION BY RMS



STEP II
POSITIONED TO TRANSFER
INTO ORBITER



STEP III
TRANSFERRED INTO ORBITER



STEP IV
POWER MODULE SECURED
FOR RETURN

ORBIT RECOVERY SEQUENCE

Figure 5-7 On-Orbit Maintenance

5.2.1.1 Deployment and Checkout Operations

The initial placement of the PM in orbit will consist of deployment/berthing and checkout operations performed in three phases as shown in figure 5-8. Detailed deployment tasks are itemized in this figure. Under the direction of an astronaut operator, the remote manipulator system (RMS) will be used to remove and deploy the PM from the cargo bay. After deployment from the cargo bay, the PM will be berthed to the orbiter and an integrated Orbiter/PM systems checkout will be performed to verify PM operational capability.

The signification time-critical item during this sequence is the spinup time for PM CMG reaction wheels. Normal spinup time to achieve 9,000 rpm operating speed is 12 hours. CMG spinup will be initiated during the pre-deployment checkout phase. Estimated sequence timelines for the three phases are as follows:

Pre-deployment	12 hours
Deploy and dock	30 to 60 minutes
Post-docking checkout	4 to 6 hours

Checkout operations will be performed in each of these phases. The significant checkout tasks will be performed during the post docking phase. During this phase, after berthing is completed, all systems of the PM will be commanded on. Performance of all PM systems and PM/Orbiter power, heat transfer, and attitude stabilization interfaces will be evaluated for varying power-heat load conditions and attitude orientations. Primary checkout control and monitoring can be from the Orbiter aft crew station using PM display/control instrumentation. Performance data will be relayed to ground stations via RF for determining detail subsystem performance. PM operational readiness will be verified through this data.

During deployment and berthing operations, the Orbiter maintains RF link control of the PM and in the post berthing phase the command and control of the Orbiter is by hardline link to the Orbiter. All disconnect/reconnect

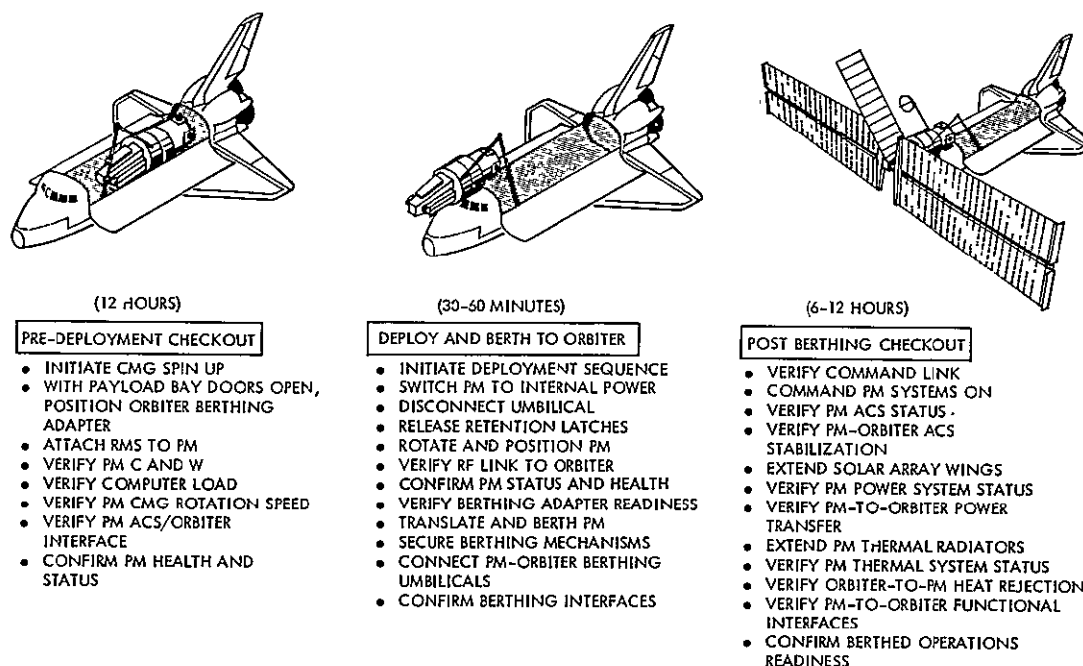


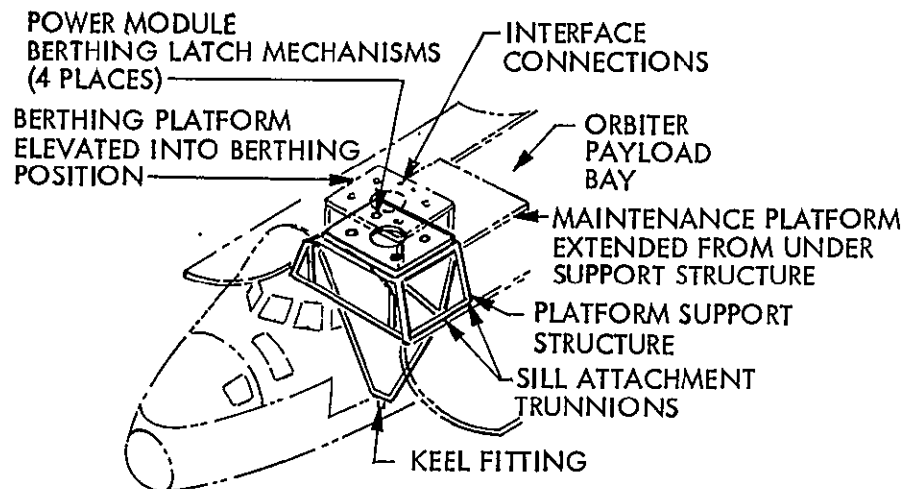
Figure 5.8 25 kW Power Module Initial Flight Deployment/
Berthing Checkout Operations

mechanisms are automated through Orbiter control. RMS attach-disconnect and manipulation will be by an astronaut operator at the Orbiter RMS station. The Power Module radiators and solar array will be in stowed position during pre-deployment, deployment, and berthing sequences. During PM positioning and berthing, the PM CMGs will stabilize the PM and all active guidance and maneuvering will be done by the Orbiter.

When the Orbiter is ready to release the PM, the solar array and radiator panels of the PM will be retracted. The berthing platform holddown mechanisms will be released. The RMS will then extend and release the PM.

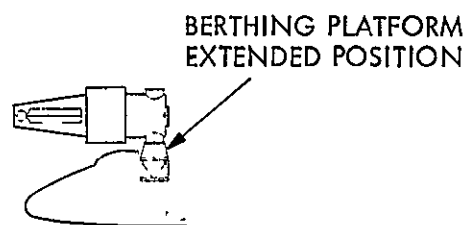
5.2.1.2 Berthing Operations

Berthing features for the Power Module/Orbiter are shown in Figure 5-9. The berthing system consists of a table supported on a sill platform and frame

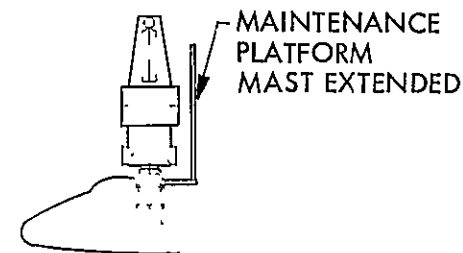


OPERATIONS

- DUAL MODE POSITIONING
- RMS FOR CAPTURE (GRAPPLE), TRANSLATION, POSITION ALIGNMENT, BERTHING MATE
- RELEASE VIA RMS
- EVA USE AFTER BERTHING
- NO ACS PERFORMANCE DEGRADATION



SORTIE MODE



MAINTENANCE MODE

DESIGN

- ORBITER COMPATIBLE
- POSITION FLEXIBILITY ALONG LENGTH OF PAYLOAD BAY
- LIGHTWEIGHT GUIDE MATING CONES AND LATCH MECHANISMS
- PLATFORM OFFSET OVER ORBITER FOR CLEARANCE AND RMS KINEMATICS
- AUTOMATED UMBILICAL CONNECT AND DISCONNECT
- ROTATIONAL PLATFORM FOR MAINTENANCE POSITIONING
- INCORPORATES MAINTENANCE PLATFORM AND ACCESS MAST

Figure 5-9 Berthing Operation Concepts

assembly. It is attached to three trunnions and a keel fitting in the Orbiter payload compartment. The berthing system can be positioned where required along the payload bay. A rotation ring with latch mechanisms and a guide system is mounted on the table. A maintenance platform with a folded access mast is stowed under the sill platform.

The berthing platform will be utilized to attach the Power Module to the Orbiter for the sortie mode and maintenance mode type missions. The sortie mode berthing orientation is "over the nose" of the Orbiter while the maintenance mode orientation is vertical "tail down" to the Orbiter.

In a typical operational sequence the Orbiter will arrive in the vicinity of the PM, which will be in a free-flying mode, and will verify and/or condition the PM for berthing. All PM radiators, solar arrays, and antennas will be retracted and the CMGs will stabilize the vehicle during the berthing maneuvers. All active maneuvering will be performed by the Orbiter. The Orbiter will rendezvous with the PM and will use the RMS to grapple and capture the PM. The RMS will then be used to translate the PM and guide it into alignment position over the guide mating attachment cones. Then the RMS will berth the PM to the berthing ring and the latch mechanisms will be engaged, thus securing the PM. After berthing, the interface umbilicals will be automatically connected. The RMS can then be released and stowed or used for other tasks as required during maintenance activities. Berthing release will be performed in a reverse sequence.

5.2.2 Orbital Maintenance Operations

Basic to the design of the multi-kW (25, 50 and 100 kW) Power Module Systems is the capability to complete the mission objectives through on-orbit replacement, repair or maintenance of system components. In addition, on-orbit growth (Scenario I evolution) must consider handling and installation of the 50 kW kit to achieve a 100 kW power system. Past experience has indicated an

EVA capability is a cost effective method to assist in achieving mission success. On-orbit maintenance utilizes the EVA crewman's capability to perform a wide variety of tasks in the following EVA categories:

- o Planned before launch to complete a mission objective (scheduled maintenance).
- o Unscheduled but decided upon during a flight to achieve payload operation success.
- o Contingency or unplanned to perform manual override or backup, to insure the safety of all crewmen.

The primary objectives of on-orbit EVA maintenance are to develop the capability to:

- o Minimize program cost
- o Reduce design/operations complexity
- o Improve operational reliability
- o Reduce development uncertainties
- o Develop flexibility in candidate maintenance approaches
- o Provide for maximum safety of maintenance and flight crews

Essentially, an EVA crewman can perform the same tasks on orbit that he can perform on the ground, given the adequate restraints, working volume, tools and compatible man/machine interfaces.

Analysis of the Scenario I evolution and attendant maintenance modes dictated that the following key issues must be resolved.

AREAS	APPROACH
o Safety to Crew, Orbiter	Design emphasis
o RMS vs Crew vs Combination	Combination
o Docking or Berthing	Berthing
o Deployment	RMS

AREAS	APPROACH
o Retract/extend deployable device, Auto vs Manual	Automatic with Manual Backup
o Axial vs Radial equipment changeout	Radial-Rotate PM/S/A
o Crew EVA Timelines	One EVA-Two Crewmen
o High Power Transfer	Design-Procedures

These issues became the catalyst of crew systems maintenance and design development. All replacement modules are designed for one crewman operation although the buddy concept is used to assure maximum safety. However, this second EVA crewman will assist the maintenance crewman and RMS operator as necessary.

Equipment/module packages are grouped as replaceable assemblies e.g., 5 batteries per module. Redundancy is incorporated in critical components e.g., CMG's-two of three can continue the mission successfully. Packaging of components into Orbital Replaceable Units (ORU) to reduce the number of removals/replacements is a basic design process. ORU design must allow the most simple and rapid method for EVA changeout; must require the least training/simulation; and must create the least damage with minimal crew error factors.

The guidelines used to develop maintenance concepts were:

- o Two crewmen will be utilized to perform EVA maintenance tasks, ideally within a 6-hour time frame.
- o Operations by one EVA crewman (second EVA crewman backup)
- o Standard NASA support equipment, such as tools, tethers, restraints, workstands, lighting, will be considered design baseline.
- o Universal or multimission ancillary equipment will be used to minimize crew training, simplify operational requirements, and provide the most cost-effective approach.

- o As design goals, all replaceable units will have similar or compatible man-machine interfaces featuring the same unit mounting and removal techniques, modular in size and shape, and, or course, capable of being transferred/handled within the crewman's physical capabilities and time constraints.
- o Adequate EVA/maintenance design requirements will be "built-in" to insure optimum EVA timeline usage by both crewmen.

Maintenance features have been incorporated into the basic PM design concept. These features will also enhance on-orbit growth. Major elements of subsystem equipment are grouped within one location in the core vehicle and located with consideration for accessibility via EVA. Equipment/assist hand rails will be incorporated into the PM design, located along major access areas. The concept design for replacement module ORUs will be for one crewman removal/replacement.

Appendix C reference 6, lists the present ORUs estimated for the 50 kW Power Module. Many of these may be grouped into modules by the design process which will reduce the total number of ORU's. The overriding consideration is knowing what has degraded or failed and needs to be replaced. Thus, fault isolation/diagnostics dictate the optimum ORU.

The maximum weight to be handled is the 2565 lbs of the radiator. At this time it is not now known whether the radiator may be removed in several ORU's rather than one.

Time estimates indicate that from 6 to 12 ORU changeouts may be accomplished during one EVA.

5.2.3 Orbital Growth Operations

Basic to the design of the 50 kW growth to 100 kW is the capability to complete mission objectives through on-orbit installation and later removal/replacement of system components. Therefore, packaging of the 50 kW kit in

the Orbiter payload (P/L) bay is the paramount consideration. The 50 kW kit consist of three major modules to be installed which reduces the EVA time to accomplish the complete installation task.

The primary objectives in establishing a feasible sequence of operations are to:

- o Determine a safe, effective means of installation.
- o Reduce design/operations complexity.
- o Simplify test and quality assurance programs.
- o Assure efficient, safe, cost-effective system design.

The EVA sequence of removal and installation is illustrated in Fig. 5-10. The growth requirements are such that the "old" 50 kW S/A must be removed in two separate parts and then the "new" 50 kW kit installed. At first glance this would require two RMS's and a complex sequence of operations as well as excessive time to accomplish.

It is more cost effective to assume one RMS, a work station and hold attachments for both modules. The hold attachments are holding fixtures which will be positioned in the cargo bay and will be used to temporarily "hold" the solar arrays during the removal-installation sequence. Location of the hold devices is TBD. This is the approach used in the deriving EVA timelines. The time in parenthesis in each functional block do not necessarily indicate the time required to do the task because parallel tasks by the two EVA crewmen and the RMS operator may be occurring during any installation sequence. Only one rest sequence is used (5 minutes every hour is recommended) because in some sequences of operations one of the EVA crewmen can rest while awaiting completion of a task by the other crewman. Detailed step-by-step sequences are outlined in Appendix C reference 6. The total 50 kW kit installation task is estimated to require approximately three hours (2 crewmen for one EVA).

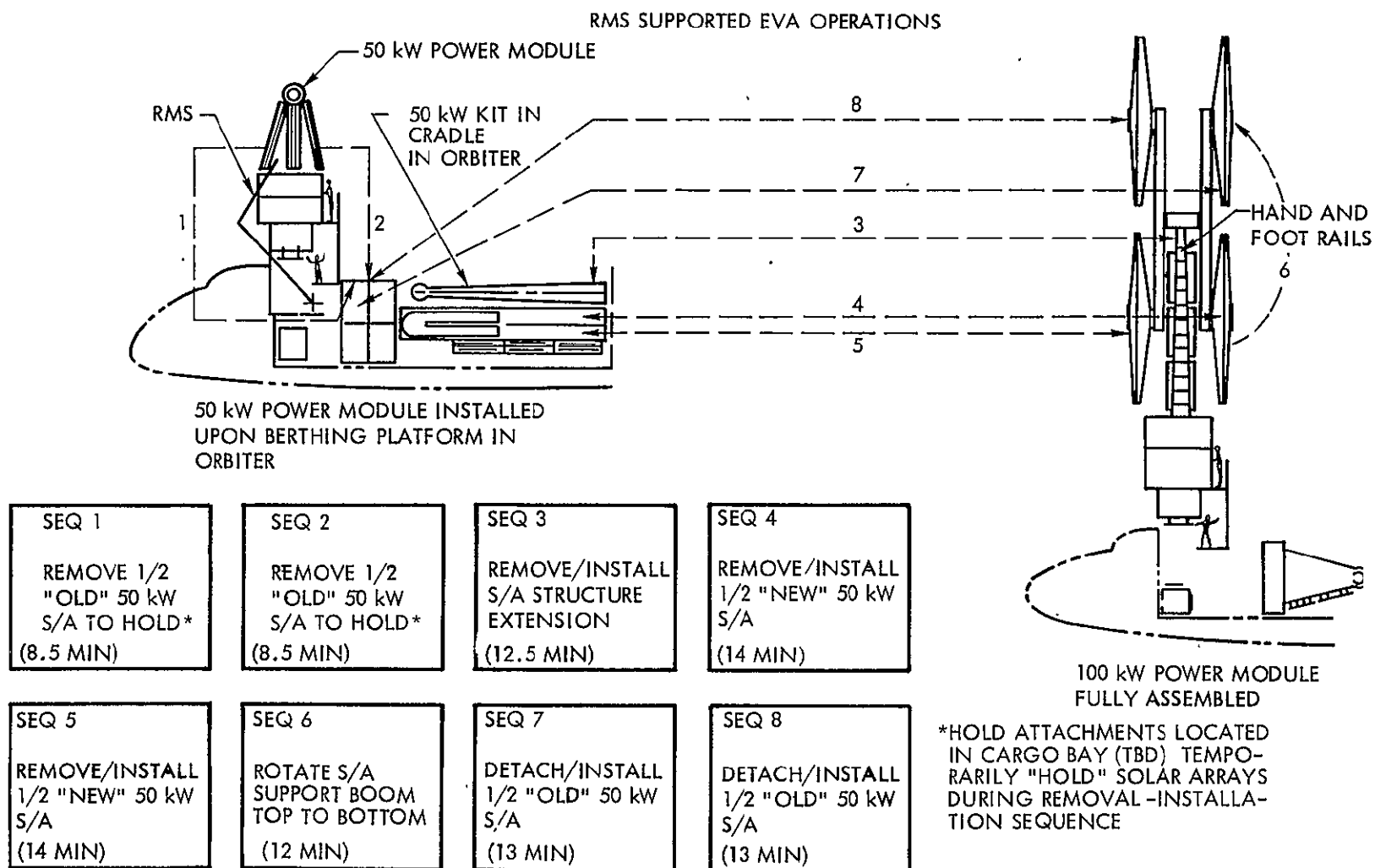


Figure 5-10 100 kW Power Module Assembly Sequence

5.3 LOGISTICS

The prime goal of the logistics support effort is to ensure PM operational readiness with economical support resource allocation. The defined requirements for logistics services, spares, maintenance, operating manuals, facilities and equipment are divided into four major categories: Inventory Management/Spares Selection, Transportation, Training/Procedures and On-Orbit repair.

Data items assigned to Logistics are logged and accounted for by monitoring the due date list and requests are made for the stored masters in time to permit preparation of revisions as necessary. Thus, Logistics develops detailed tasks, schedules, and budget planning which is the blueprint for all logistics activities and tasks.

All modules for installation, ground or on-orbit repairs will have top-down breakdown appropriately identified. This provides a uniform method for tracking to the next higher assembly and spare and repair parts (S/RP) identified uses the following groundrules:

- o S/RP required to support tests during development and to support the first flight article, including the PM and S/A, and SSE, will be acquired in minimum quantities. Release of S/RP orders will be scheduled to the extent practical to provide economies of purchase or manufacture concurrently with test and/or end item hardware.
- o Spare and repair parts will be positioned at the using site 30 days prior to need date.
- o High-cost items and those subject to a high incidence of design change or change in performance or material specification will be procured incrementally as necessary to support a particular test. Others having low probability of malfunction will be procured in minimum quantities to protect against schedule delay.

- o Release of S/RP orders to support the first and subsequent production/operational systems will be delayed until late in the development Phase.

5.3.2 TRANSPORTATION AND PACKAGING

Transportation, packaging, storage and handling requirements for the PM, S/A, GSE, and spares and spare parts will be Logistics responsibility. From the factory verification sequence to on-site delivery (airfield), PM, Pre-installation preparation (O/C), Orbiter integration (OPF), appropriate/spares and GSE (cranes, transporter, slings, etc.) will be made available. Subcontractors will support as required.

5.3.3 TRAINING AND PROCEDURES

Logistics specifies training equipment, materials, facilities, and services in all phases of the PM program. Training includes operations P/L C&D, on-orbit maintenance, and ground maintenance. Course lists, training aids or devices for each course will be developed. Ground crews will perform as a team of specialists.

Manuals or procedures for LRUs & ORUs will start from design "on-the-boards" thru mockup training and simulation.

Mockup development is a design and operations verification tool used by each of the major engineering and system disciplines. Neutral buoyancy simulation is expensive, requires metal (or suitable substitute) mockups, must be carefully planned, and requires substantial test support equipment and personnel. However, 1-g testing can be initially accomplished with soft mockups for preliminary layout and interface analysis. Furthermore, soft mockups (foamcore, wood, etc.) permit simple and rapid reconfiguration at minimum expense.

Figure 5-11 represents the three simulation techniques recommended for the PM program. NASA/MSFC has neutral buoyancy facilities ideal for simulation types 2 and 3. All the simulation types support each other and in actuality are a constant iterative process. The fall-out results assist in solving the ground and on-orbit repair/growth man-machined procedures. The schedule shows present estimates of when the various types of simulation must begin. The time periods for simulation will continue until a satisfactory resolution is achieved.

5.3.4 ON-ORBIT REPAIR

In addition to ensuring ORUs are available as required, the Logistics function is to define the simulation (semi-hard mockups, neutral buoyancy) required to establish effective on-orbit repair. Data will be used to clarify on-orbit procedures and establish time-to-accomplish the on-orbit tasks.

5.3.5 STORAGE REQUIREMENTS

Primary spares storage will be at the factory where PM installation and refurbishment will be accomplished. The GSE (portable test consoles, etc.) will be transported to the launch site as required. Minimum storage will be required at the launch site (for SSE) with the exception of an environmentally controlled facility for batteries.

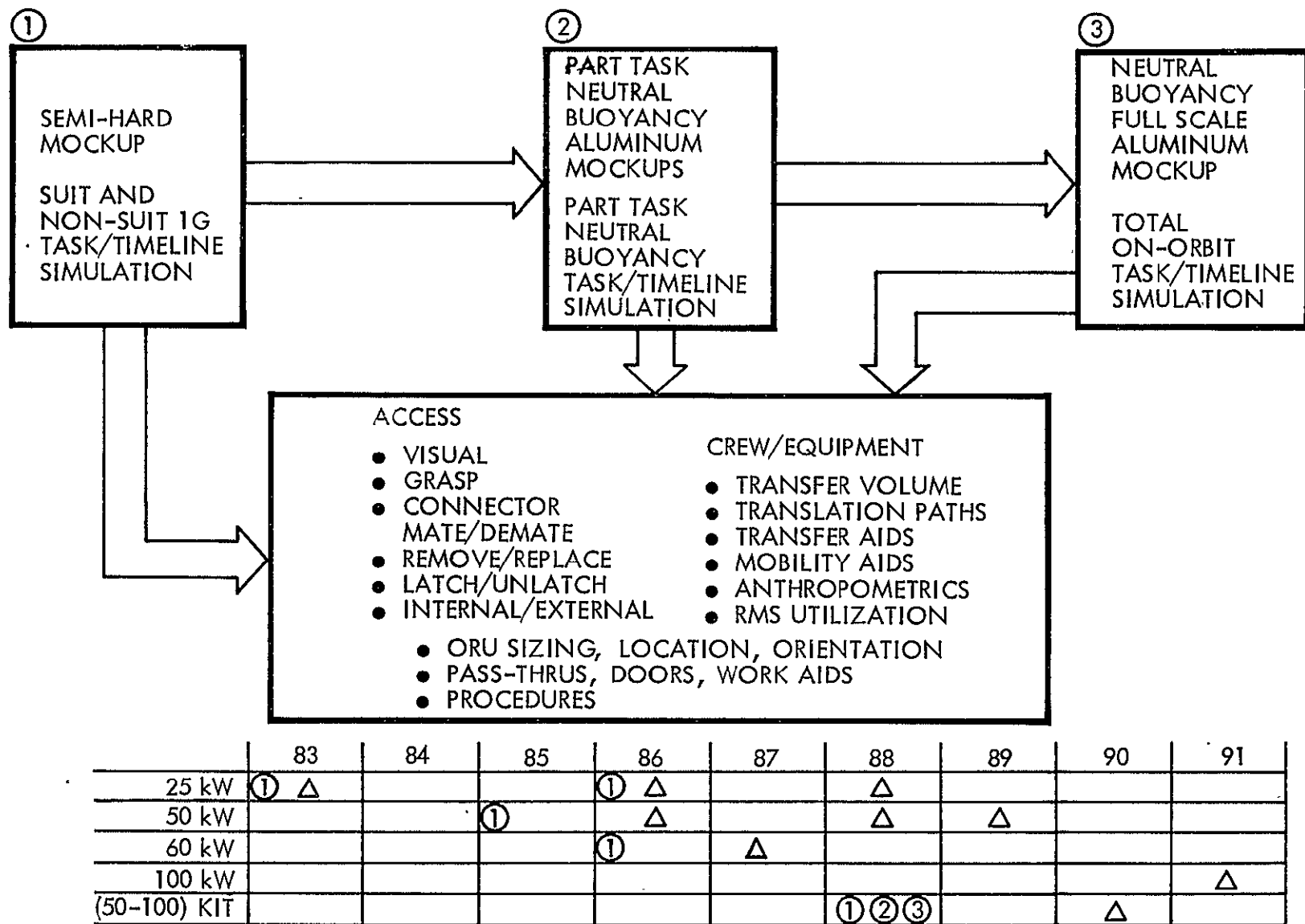


Figure 5-11 Power Module/Solar Array Simulation Requirements

Section 6

PROGRAM FACILITIES PLANS

6.1 GENERAL

A general survey of facilities requirements to support the Development/Acquisition Phase of the 25 kW Power Module was performed during the Study. It was concluded that most companies engaged as prime contractors for the development and production of spacecraft should have existing facilities which substantially meet the general requirements for engineering, manufacturing, test, launch support, operational support and refurbishment operations associated with the 25 kW Power Module and its logical evolutions.

6.2 MANUFACTURING/ASSEMBLY FACILITIES

The only unique facility requirement for the Power Module Programs derives from prospective automation of the solar array panel and wing assembly operations. A number of concepts and procedures are competitively available and being explored by industry in anticipation of volume production requirements with significant cost sensitivity. The significance of the need for high volume solar panel production capability, with high reliability and low cost is reflected in the present NASA procurement concept for separate solar array procurement for a number of programs including the 25 kW Power Module requirements.

6.3 GROUND OPERATIONS FACILITIES (KSC)

During this study, a visit was made to Kennedy Space Center (KSC) to review STS facilities and the accommodations which are being developed for processing payloads for the Shuttle.

Results from the visit and analysis of Reference 4 indicate that the existing and planned facilities (modifications) will be satisfactory to support PM

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ground operations. No new facilities or modifications to existing facilities will be required.

A summary of facilities to be used for PM processing is given in Figure 6-1. The most significant facilities are the Operations and Checkout Bldg. and the Orbiter Processing Facility.

Operations and Checkout (O&C) Building

The major facility for PM processing will be the O&C building (Bldg. #177-355) at KSC. The use of this facility will allow the PM to be processed in a horizontal attitude. Since this facility is now being modified for Spacelab processing in a horizontal attitude the PM ground processing can readily be accommodated. Spacelab checkout stands with fixed rails and adjustable trunnion supports can be used by the PM by making use of adaptor support GSE which can adapt the PM structure to these fixed rail support stands. As part of the STS payload accommodations modifications, the horizontal Cargo Integration Test Equipment (CITE) checkout stand will be located in the O&C building to conduct pre-orbiter installation cargo integration tests. The PM will use this CITE to verify compatibility of PM-Orbiter interface before installation in the Orbiter.

Orbiter Processing Facility (OPF)

In conformance with the baseline NASA concept, the PM and its Space Support Equipment (SSE) will be installed in the Orbiter in a horizontal attitude at the OPF.

The planned payload strongback lifting fixture and facility overhead crane will be used to install the PM into the Orbiter cargo bay. Small size items of SSE such as display panels and wire harnesses can be hand carried on board and installed in the Orbiter. Large size items of SSE such as the PM berthing adaptor will be installed in the Orbiter cargo bay using the overhead cranes to lift and lower these items into the orbiter.

PROCESSING TASK	FACILITY/PM ACTIVITY					
	AIRSTRIp	OPERATION AND CHECKOUT BLDG (O&C)	ORBITER PROCESSING FACILITY (OPF)	VEHICLE ASSEMBLY BUILDING (VAB)	LAUNCH PAD	LAUNCH CONTROL CENTER
ON SITE DELIVERY	DELIVERY OF PM FROM FACTORY					
PM PRE-INSTALLATION PREPARATION		• REC INSP • S/A INSTL • BATT SERVICE/BATT INSTALLATION • PM CHECKOUT • FINAL WT & CG • CARGO INTEG TEST (CITE) • LOAD XPORTER • SSE PREPS/STORAGE • GSE MAINTENANCE				
INTEGRATION OF PM INTO ORBITER			• INSTL & VERIFY PM SSE • INSTL PM • PM/ORB INTEG TEST • P/L BAY FINAL CLOSE OUT			
BUILD UP STS TO LAUNCH				• PM INACTIVE • TRICKLE CHARGE BATT (TBD)		
PRE-LAUNCH VERIFICATION					• LAUNCH READINESS TESTS • CMG SLOW SPIN • TRICKLE CHARGE BATT (TBD)	
PRE-LAUNCH MONITOR/CONTROL						• PM STATUS HEALTH • PWR TRANSFER • CMG SPINUP • COMPUTER LOAD • COMPUTER VERIF
ORBITER RETURN - POST FLIGHT EQUIPMENT REMOVAL		• INSPECT/PREPARE PM FOR SHIPMENT • INSPECT, STORE, MAINTAIN SSE	• REMOVE PM • REMOVE SSE			

Figure 6-1 PM Ground Operations and KSC Facility Use

Removal of PM equipment after flight will be performed in the OPF making use of facility support equipment in essentially a reverse sequence from the installation sequence. Items of SSE will be removed after each flight and recovered PMs will be removed when returned from orbit.

Section 7

7.1 RELATED PROGRAMS DATA/TECHNOLOGY REQUIREMENTS

Implementation of the growth versions to this program plan may be dependent upon the timely and successful implementation of a number of associated development programs which have much broader application than solely the Power Module Program. Among these are:

- o Ni-H₂ Batteries
- o GaAs Solar Cells
- o SSM Primary Structure
- o Composite Materials for Large Structures
- o SEOS Technology Program
- o SEPS Orbital Flight Test Program
- o EVA Concepts
- o Document Module - Pressurized

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Section 8

8.1 REFERENCES

1. LMSC-D614921A, Final Report, 25 kW Power Module Evolution Study, Part I: Payload Requirements and Growth Scenarios, dated 1 August 1978
2. LMSC-D614944-1, Final Report, 25 kW Power Module Evolution Study, Part III: Conceptual Designs for Power Module Evolution, Volume 1: Power Module Evolution, dated 27 January 1978
3. LMSC-D614944-6, Final Report, 25 kW Power Module Evolution Study, Part III: Conceptual Design for Power Module Evolution, Volume 6: WBS and Dictionary, dated 27 January 1979
4. NASA KSC K-STSM-14.1/KSTSM-09, Vol VI, March 1978, Launch Site Accommodations Handbook for STS Payloads
5. Shuttle Turnaround Analysis (STAR) No. 015, dated June 5, 1978, prepared by Rockwell Operations Planning and Approved by KSC/SP-OPN
6. LMSC-D614944-4, Final Report, 25 kW Power Module Evolution Study, Part III: Conceptual Design for Power Module Evolution, Volume 4: Design Analysis, dated 27 January 1979

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APPENDIX A
WORK BREAKDOWN STRUCTURE

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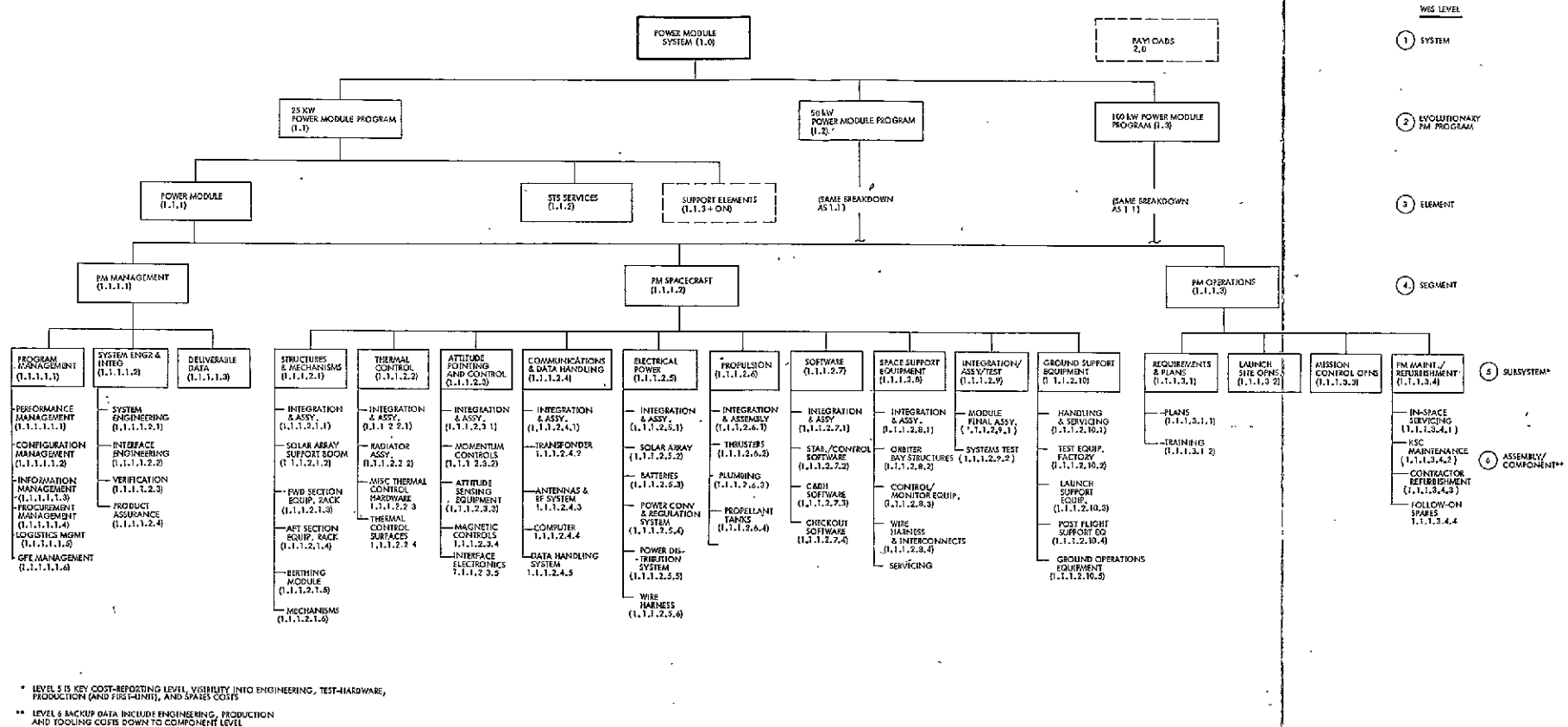


Figure A-1 Work Breakdown Structure

APPENDIX B
ACRONYMS AND ABBREVIATIONS

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ACRONYMS AND ABBREVIATIONS

ACS	Attitude Control System
APCS	Attitude Pointing and Control Subsystem
C&DH	Communication and Data Handling Subsystem
CB	Construction Base
CDR	Critical Design Review
CEI	Contract End Item
CITE	Cargo Integration Test Equipment
CMG	Control Moment Gyro
EO	Earth Observation
EPS	Electrical Power Subsystem
EVA	Extra Vehicular Activity
FV	Flight Vehicle
GEO	Geosynchronous
GFE	Government Furnished Equipment
GSE	Ground Support Equipment
GSFC	Goddard Space Flight Center
IBM	International Business Machines
I/F	Interface
IOC	Initial Operational Capability
JSC	Johnson Space Center
KSC	Kennedy Space Center
LEO	Low Earth Orbit
LMSC	Lockheed Missiles & Space Company
LRU	Line Replaceable Units
LS	Life Science
MCC	Mission Control Center
MP	Material Processing
MSFC	Marshall Space Flight Center
NASA	National Aeronautics and Space Administration
NDT	Non Destructive Test
O & C	Operation and Checkout
OPF	Orbiter Processing Facility

ACRONYMS AND ABBREVIATIONS (Continued)

ORU	Orbital Replaceable Units
P/L	Payload
PEP	Power Extension Package
PDR	Preliminary Design Review
PM	Power Module
PMOCC	Power Module Operations Control Center
POCC	Payload Operations Control Center
PRL	Program Requirements List
PS	Public Service
PSE	Peculiar Support Equipment
Qual	Qualification
RMS	Remote Manipulator System
S/A	Solar Array
S/C	Subcontract
S/RP	Spare and Repair Parts
SCD	Space Construction Demonstration
SEP	Solar Electric Propulsion
SMS	Structure and Mechanisms Subsystem
SPS	Space Power System
SS	Space Science
SSE	Space Support Equipment
STO	Solar Terrestrial Observatory
STS	Space Transportation System
SW	Software
TBD	To Be Developed/Determined/Defined
TCS	Thermal Control Subsystem
TDRS	Tracking and Data Relay Satellite
TDRSS	Tracking and Data Relay Satellite System
TLM	Telemetry
TRW	Thompson Ramo-Woolridge
TV	Thermal Vacuum
VAB	Veritcal Assembly Building

LOCKHEED



IBM

TRW